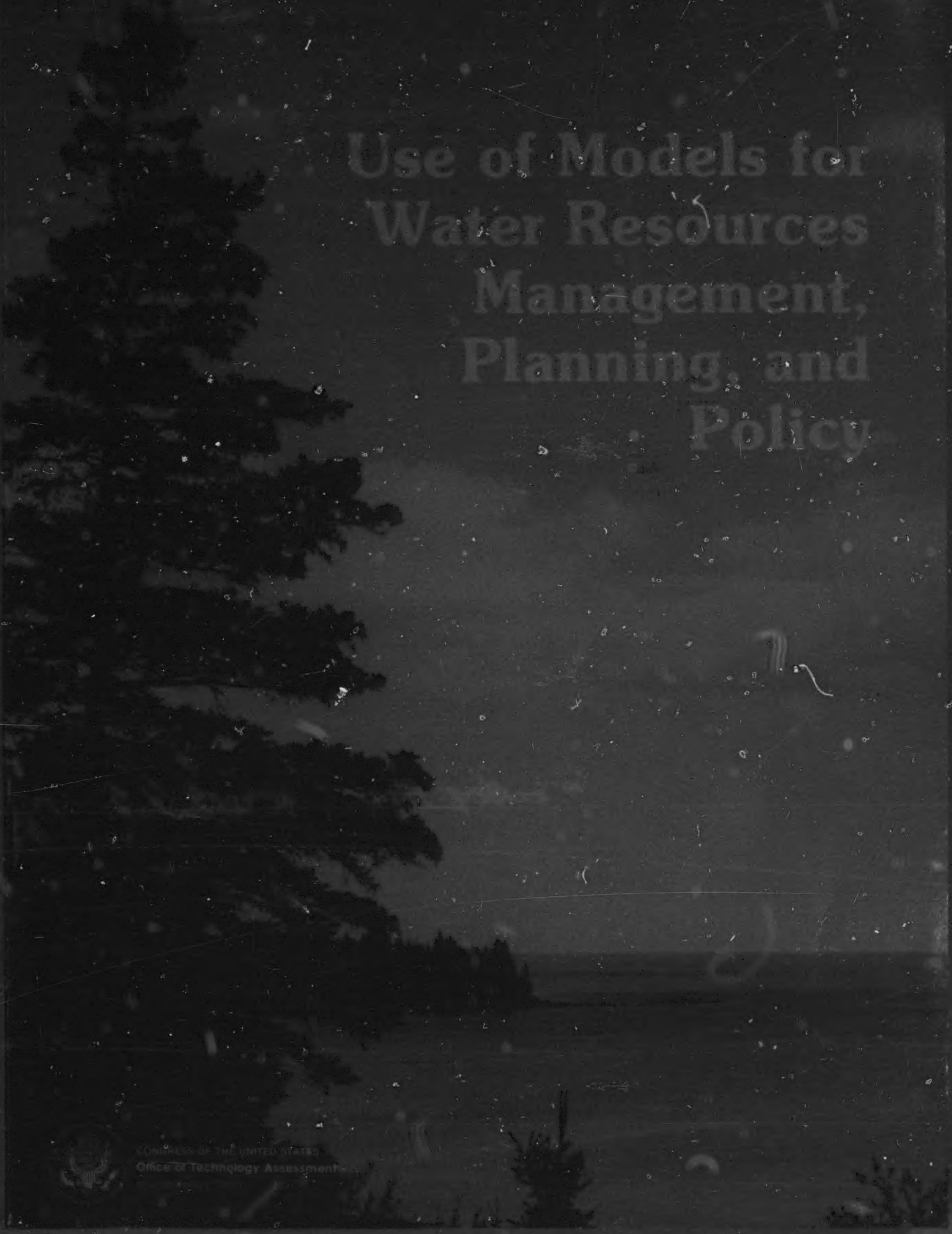
Use of Models for Water Resources Management, Planning, and Policy



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Use of Models for Water Resources Management, Planning, and Policy

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Foreword

The Nation's water resource policies affect many problems in the United States today—food production, energy, regional economic development, environmental quality, and even our international balance of trade. As the country grows, and excess water supplies diminish, it becomes increasingly important to manage existing supplies with the greatest possible efficiency. In recent years, successful management and planning of water resources has increasingly been based on the results of mathematical models.

Leaving aside the mystique of computers and complex mathematics, mathematical models are simply tools used for understanding water resources and water resource management activities. This part of water resource management, though not as apparent as dams and reservoirs or pipes and sewers, is a vital component in meeting the Nation's water resource needs. Sophisticated analysis, through the use of models, can improve our understanding of water resources and water resource activities, and help prevent wasting both water and money.

This assessment of water resource models is therefore not an assessment of mathematical equations or computers, but of the Nation's ability to use models to more efficiently and effectively analyze and solve our water resource problems. The assessment considers not only the usefulness of the technology—the models—but the ability of Federal and State water resource agencies to apply these analytic tools effectively.

The capabilities of water resource models vary greatly from issue to issue. In a number of areas, further research and development is needed, but in other areas, usable and reliable tools currently exist. However, as often occurs, these technologies have outstripped the capabilities of Federal, State, and local agencies to support and effectively use them. Today, model use is increasing the efficiency and lowering the cost of water resource management, but the potential for further improvement remains great.

This report presents options that focus on ways of improving Federal, State, and local use of available technologies to analyze water resource problems. Opportunities are identified for congressional action to improve water resource management capabilities through selective model use—throughout the Federal Government, within individual Federal agencies, and among State and local governments. The importance of water resources to the Nation's well-being, and the magnitude of potential water resource problems in the coming decades, makes this technology an important tool for assuring our ability to provide for the water needs of current and future generations.

About 40 water resources professionals from Federal and State agencies, universities, and the private sector contributed to this report. Many more provided useful comments on draft materials. OTA was also aided by representatives from 27 Federal agencies and offices, and from all 50 States, who provided information in response to OTA surveys and inquiries regarding model use, as well as by Federal, university, and private sector participants in two series of workshops on modeling issues. OTA expresses sincere appreciation to all these individuals for helping bring an imposing amount of collective wisdom to this analysis.

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- The professional societies that reviewed technical materials, including the American Geophysical Union, the American Society of Civil Engineers, the American Water Resources Association, and the National Water Well Association.

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Chapter 1

Summary, Issues, and Options

SCOPE

This assessment is intended as a guide for Congress on the potential to develop and use mathematical models to more effectively and efficiently analyze the Nation's water resource problems. Policy options are presented for improving the use of these tools within both Federal and State water resource agencies.

The assessment reviews the current technical capabilities of models; the current and potential use of models by Federal and State agencies; and general impediments to effective model development, use, and dissemination. It draws on the results of surveys of water resource professionals in 27 Federal agencies and offices, from all 50 States, and from universities and the private sector.

Mathematical models are new technologies that are increasingly being used for water analysis. The Office of Technology Assessment (OTA) focused on mathematical modeling as a means of assessing the broader issue of our ability to analyze and plan courses of action to deal with current and long-range water problems. OTA did not investigate the more traditional forms of water resource analysis that are being replaced by mathematical models, or the less commonly used physical models.

The technical capabilities of models vary greatly among the water resource issues analyzed in this report; however, **the assessment finds that models capable of analyzing many pressing water resource issues are currently available, and have significant potential for increasing the accuracy and effectiveness of information available to managers, decisionmakers, and scientists.** Institutional constraints to model use, including lack of information about available models, lack of training in model use and interpretation, lack of communication between decisionmakers and modelers, and lack of general support services, are identified as major impediments to increased model use for water resource analysis.

The full report includes:

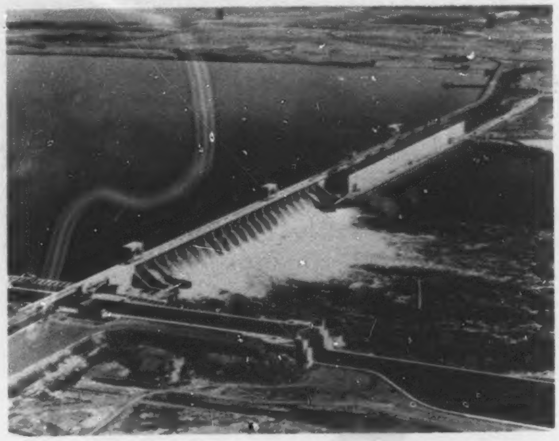
[redacted]

INTRODUCTION

Between 1950 and 1975, the Federal Government spent over $45 billion to develop, maintain, and improve the Nation's water resources;[1] expenditures have spiralled to even higher levels over the past decade. Federal efforts range from constructing dams to increase the reliability of water supplies, generate hydroelectric power, improve flood control, and provide recreational opportunities; to studies for determining whether flood plain areas are sufficiently safe to permit building activities; to providing wastewater treatment for reducing health and environmental risks due to polluted rivers, streams, and lakes.

Decisions affecting water resources are made by the Federal, State, and local governments, and by the private sector. These decisions include designing day-to-day management procedures for operating facilities most efficiently, as well as planning and implementing long-range policies for water resources management and construction. Decisions of the latter kind involve large sums of money, and may affect the availability and quality of water for many decades to come. As the Nation grows, and excess water resource capacities diminish, it becomes increasingly important to manage existing facilities, improve the efficiency of water use, and make long-range plans in ways that maximize the return on natural, capital, and human resources.

Mathematical models are among the most sophisticated tools available for analyzing water resource issues. They can use the capabilities of today's digital computers to perform and integrate millions of calculations within seconds, in order to understand and project the consequences of alternative management, planning, or policy-level activities. Models only assist in decisionmaking—they provide information that people must interpret in light of existing laws, political and institutional structures, and informed professional and scientific judgment. Nonetheless, models can significantly improve the informational background on which decisions are based, and substantially reduce the cost of managing water resources. Although the Federal Government spends approximately $50 million on water-related mathematical models annually, such tools are instrumental in planning billions of dollars of annual water resource in-



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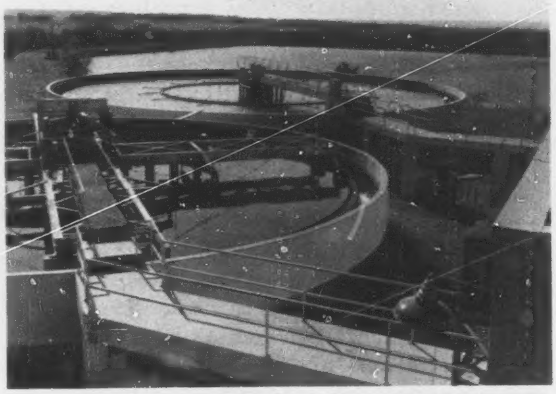

Photo credit: U.S. Department of Agriculture

Federal, State, and local governments, and the private sector, provide billions of dollars to support the construction of dams, reservoirs, and water treatment facilities. Mathematical models are becoming increasingly important in determining the need for such facilities, and in planning, designing, and operating them. Models can be used to help operate existing structures such as the McNary Dam on the Columbia River (top), as well as to develop and run new facilities like the illustrated water purification system in Duncan, Okla. (bottom) vestments, and managing hundreds of billions of dollars of existing facilities.

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[1] Viessman, et al., *The Nation's Water Outlook to the Year 2000.* The $45 billion estimate includes expenditures by the Army Corps of Engineers, the Bureau of Reclamation, the Soil Conservation Service, the Tennessee Valley Authority, and the Environmental Protection Agency's Construction Grants Program outlays.

The role of models in managing water resources has grown dramatically over the past decade—a period in which water resource management itself has become increasingly important. High rates of economic and population growth in water-short areas of the country, decreased availability of water from major ground water aquifers, and increased public concern for the quality of its drinking water, lakes, and rivers have made it even more necessary to manage water resources carefully. In addition, the issue of who is to manage water resources has gained prominence in the political arena, as ways are sought to increase States' responsibilities for assuring adequate and safe water supplies.

The magnitude of the national investment in water resources calls for systematic use of the best analytic tools available to manage this investment. Over the past 20 years, models and sophisticated data processing systems have been advanced as promising great improvements in water resources management, planning, and policy. Yet many consider that these tools have not yet lived up to earlier expectations. OTA was requested to study the use of models in freshwater resources analysis in order to determine their current capabilities, identify appropriate roles for their use, and suggest options for improving modeling efforts and model use.

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Pipelines to provide new supplies of water for the State of Arizona (top) and the New York City water tunnel (bottom) demonstrate the magnitude of the Nation's water resource needs. Reliable forecasts of an area's water requirements are critical for designing efficient and adequate water transport and distribution systems. Models can be used to estimate future demands for water, and to assist in water system design

FINDINGS

Mathematical models have significantly expanded the Nation's ability to understand and manage its water resources. They are currently used to investigate virtually every type of water resource problem; for small- and large-scale studies and projects; and at all levels of decisionmaking. In some cases, **models have increased the accuracy of estimates of future events** to a level far beyond "best judgment" decisions. In other areas, **they have made possible analyses that could not be performed empirically or without computer assistance.** Further, models have made it feasible to quantitatively compare the likely effects of alternative resource decisions. A few examples of situations in which models have been applied will illustrate their uses:

- Water in excess of amounts needed by crops is often applied to fields to leach out accumulated salts. This results in high water use and high salt loadings in irrigation flows returned to streams. New Mexico scientists developed a computer model to estimate the minimum amount of leaching water required to maintain crop yields and favorable soil salinities. The model has resulted in annual savings in water costs of $500,000 for the Pecos River basin in New Mexico. In addition, the lower irrigation return flows have reduced the salt input to the Pecos River by 235,000 tons per year.[2]

- The Clean Water Act currently requires dischargers to meet effluent—or "end-of-pipe"—standards, and, in addition, to discharge no more of a pollutant than receiving waters can safely carry, according to a fixed receiving water quality standard. Models are an effective means of projecting the receiving water quality that results from different levels of discharge, and are thus a major aid in determining what levels of discharge are permissible under receiving water standards.
- For the northern Virginia area, 1977 was the driest year since 1950. The Occoquan Reservoir serving northern Virginia was nearly empty, and daily withdrawals exceeded daily inflows. Using its extended streamflow prediction model, the National Weather Service (NWS) determined that there was a 10-percent risk of reaching emergency reservoir levels—a risk deemed unacceptable by local authorities. The model was then used to project that an acceptable 2- to 3-percent risk of reaching emergency reservoir levels would require reducing withdrawals by about 20 percent.[3] [4]
- Reservoirs are usually multiple-purpose facilities, many of whose objectives conflict or compete. Reservoir managers need to retain sufficient water to ensure an adequate future supply for users, yet must release enough for flood control purposes, as well as to ensure adequate low-flow levels to protect aquatic life and minimize the cost of pollution control downstream. Additional objectives include maximizing hydropower production (by releasing water) and recreational opportunities (retaining water for reservoir lake users, and releasing water for stream and downstream lake users). Mathematical models have been used on many of the Nation's major river systems to address conflicting use demands by suggesting optimal amounts and timing of reservoir releases.
- Cornell University investigators developed a systems optimization method to design a sewer network for the Long Island Regional Planning Board. The resulting analysis indicated that a sewer network that would meet community needs could be built and operated for $40 million less than could a design developed by a firm using conventional analytical methods.[5]

Models are often the best available alternative for analyzing complex resource problems. While many of the economic and social factors in water resource decisions cannot be fully enumerated, models can be used to integrate the available data, and provide estimates of future effects and activities. Such estimates are highly useful in evaluating the consequences of different resource policy options, and are often less expensive than conducting comprehensive surveys and using other traditional approaches.

Models have the potential to provide even greater benefits for water resource decisionmaking in the future. As models are refined and receive wider acceptance, **they will be able to increase the efficiency of water resource management and encourage cost-effective decisionmaking.** Such models can do much to increase the rationality of regulations and the standard-setting process, and can generally provide a sound scientific basis for water policy. The following examples illustrate the potential benefits of future expansion in model use:

- Between 1950 and 1975, the Tennessee Valley Authority (TVA) spent over $2 billion for water resources development and management. Improving rainfall forecasting and reservoir scheduling can make a very significant contribution to the benefits that accrue from these water development projects. Recent studies on six TVA reservoirs found the potential for a 20-percent improvement in operations and annual savings of $4 million through the implementation of a system of reservoir scheduling models.[6]

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[2] *Impacts of the University Water Research Program,* Task Force on Research and Education in Water Resources, U.S. Department of the Interior, March 1981, p. 9.

[3] D. C. Curtis and J. C. Schaake, Jr., "The National Weather Service Extended Streamflow Technique." Conference on Reservoir System Regulation, ASCE, Boulder, Colo., Aug. 14-17. 1979.

[4] D. P. Sheer, "Analyzing the Risk of Drought: The Occoquan Experience," *Journal of the American Water Works Association,* May 1980.

[5] *Impacts of the University Water Research Program,* op. cit., p. 4.

- NWS estimated that the installation of a $200,000 modeling system to forecast floods on the Connecticut River basin would provide a reduction in flood damages exceeding $1.5 million per year.[7]
- Models assist farmers in scheduling irrigations to optimize water conservation while maintaining crop productivity. In Nebraska, improved irrigation scheduling has resulted in 25- to 35-percent savings in water pumped and energy costs per year.[8]

Water resource models vary greatly in their capabilities and limitations and must be carefully selected and used by knowledgeable professionals. Some models are designed for management within small watersheds; others are used in planning for large geographical areas. Some are designed to provide highly accurate numerical estimates; others will provide only general approximations. Some models are designed for situations in which data are scarce; other models require large amounts of data. In some instances, decisionmakers need only "ballpark" accuracy to make decisions, but in other instances model accuracy may be extremely important. A decisionmaker may require a different model in each case, even though similar kinds of problems are being analyzed.

Since modeling is a rapidly advancing and highly specialized field, **it is extremely difficult for decisionmakers and managers to stay abreast of new developments,** or even to fully understand the capabilities and limitations of the tools they currently employ. Under such circumstances, a certain amount of model misuse and mistrust is virtually inevitable. A manager who uses a given model to analyze a situation it was not designed to address, or who overrelies on the accuracy of model results, may wrongly reject any future use of models. Managers may also perceive models as an undesirable constraint to their authority and decisionmaking capabilities. However, models are most effectively used as an *aid* to decisionmaking, rather than as a *substitute* for the decisionmaker's judgment.

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Agriculture accounts for over 80 percent of U.S. water use. Critical shortages of water for irrigation in many areas of the country make models for scheduling irrigation a valuable tool for stretching limited and increasingly expensive supplies. These models determine when plants require water, and how much they will need; some can estimate reductions in crop yields if irrigation is delayed or reduced

Models are not explicitly required in any Federal water resource legislation, but they are often the method of choice to meet the requirements of legislation. Many current laws regarding water resources require analytical work normally done in whole or in part by models. Major Federal legislation associated with model use at Federal, State, or local levels includes:

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[6] W. D. Wunderlich, "Planned Enhancement of Water Management Methods for the TVA Reservoir System," paper presented at the National Workshop on Reservoir Systems Operation, American Society for Civil Engineers, Aug. 13-17, 1979.

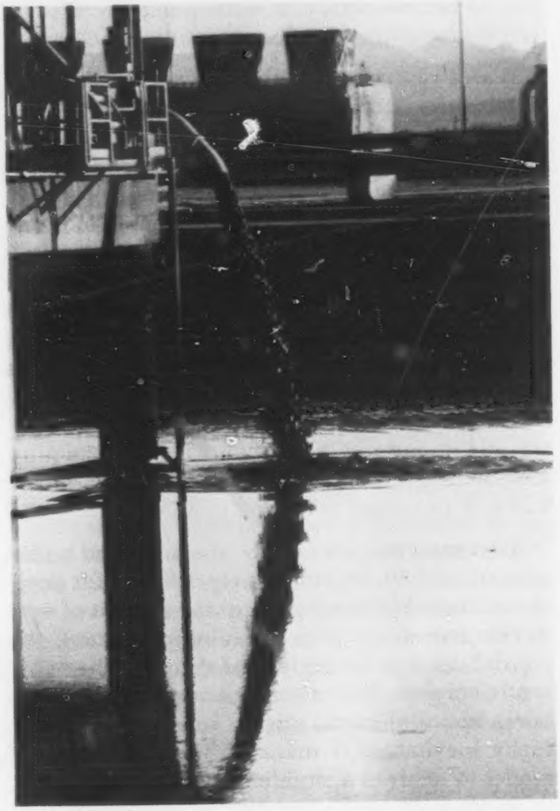
[7] H. J. Day and K. K. Lee, "Flood Damage Reduction Potential of River Forecast Services in the Connecticut River Basin," NOAA Technical Memorandum NWS HYDRO-28, February 1976.

[8] *Impacts of the University Water Research Program,* op. cit., p. 13.

- Clean Water Act (Public Law 95-217)—sections 107, 201, 208, 209, 301, 302, 303, 307, 311, 314, 316, 404, and 405;
- Safe Drinking Water Act (Public Law 93-523)—sections 1412, 1421, 1422, 1424, 1443, and 1444;
- Toxic Substances Control Act (Public Law 94-469)—sections 4, 5, and 6;
- Resource Conservation and Recovery Act (Public Law 94-580)—sections 1008 and 8006;
- Endangered Species Act (Public Law 93-205)—section 7;
- Surface Mining Control and Reclamation Act (Public Law 95-87)—sections 506, 510, and 515;
- Soil and Water Resource Conservation Act (Public Law 95-192)—sections 5 and 6;
- Water Resources Planning Act (Public Law 89-80)—section 102;
- Coastal Zone Management Act (Public Law 94-370)—section 305;
- Executive Order No. 11988 (Floodplain Management);
- Flood Control Act of 1936 and Amendments—sections 1, 2, and 3;
- National Flood Insurance Act of 1968—section 73;
- Water Research and Development Act (Public Law 95-467)—section 1360;
- Federal Reclamation Act of 1902 and Amendments—43 U.S.C. 421 and 422;
- National Environmental Policy Act (Public Law 91-190)—sections 102 and 103; and
- Atomic Energy Act of 1954—10 CFR 20, 50, 61.

In translating legislative requirements into management practices, agencies often recommend procedures that depend on the use of models. The Clean Water Act, for instance, requires States to determine the "total maximum daily loads" for those sources of pollutants that cannot meet water quality standards through effluent limitations regulations. This requires States to predict the water quality resulting from a number of point-source loadings—a responsibility that implicitly requires the use of "wasteload allocation" models. EPA's Waste Load Allocation Guidance Memorandum (Sept. 5, 1979) strongly encourages the use of models for performing wasteload allocations. The memo reads:

> The link between wasteload allocations and stream standards is a mathematical model to predict water quality as a function of waste discharges. Such models exist and are integral parts of the methodology.[9]



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Models are important tools for determining whether individual point-sources of water pollution will prevent rivers, lakes, and streams from meeting Federal water quality standards. Using models, planners can determine what levels of discharge would be acceptable *before treatment facilities are installed;* such information is extremely valuable for designing effective treatment strategies

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[9] "Funding of Waste Load Allocations and Water Quality Analyses for POTW Decisions," Construction Grants Program Requirements Memorandum, U.S. Environmental Protection Agency, PRM No. 79-11, Sept. 5, 1979, "Preliminary Technical Guidance for WLA Studies," p. 4.

Developing and using models is a complex undertaking, requiring personnel with highly developed technical capabilities, as well as adequate budgetary support for computer facilities, collecting and processing data, and numerous additional support services. Such capabilities presently reside primarily within the Federal Government, or are secured from the private sector with Federal funding. For fiscal year 1979, direct and indirect **Federal expenditures in support of model development, dissemination, and use for water resources are estimated at $40 million to $50 million annually.** The Army Corps of Engineers, the U.S. Geological Survey (USGS), and the Environmental Protection Agency (EPA) are the principal agencies involved in water resource modeling activities, and together they account for approximately 70 percent of the funds spent in support of water modeling at the Federal level. **These expenditures represent an ongoing investment in information that supports and improves expenditures of billions of dollars annually for water resource development and management.**

Federal training and assistance is also important in assuring the continuing availability of hydrologists, engineers, and modelers with expertise in water resource issues. The demand for well-trained water resource professionals at Federal, State, and local government levels, as well as in the private sector, far exceeds the number of individuals who graduate annually with relevant skills from American colleges and universities. Federal support for university-level research and training, through the University Water Research Program of the Department of the Interior, amounted to about $11 million in fiscal year 1980. In addition, a number of Federal agencies offer important training opportunities in water resources analysis and modeling for Federal and non-Federal employees alike. While such training is often critical for keeping professional employees abreast of developments in these fields, current levels of instruction are clearly insufficient to meet the growing needs of Federal, State, and local personnel.

Virtually all Federal modeling activities are currently managed on an agency-by-agency basis. Little coordination of model development, dissemination, or use occurs among Federal agencies, and effective joint modeling efforts are rare. Agencies generally have little information about models available through or being developed by other agencies; consequently, agencies tend to develop new models before taking advantage of previous or ongoing modeling efforts of other agencies. While independent agency-level development may produce tools that are more responsive to specific agency needs, the lack of cooperative development has often resulted in agencies being unable to muster the resources to adequately develop and support needed models. Testing models is a difficult, expensive process and very often a major barrier in the way of model use. OTA found instances in which more than one agency had developed similar models, none of which were used for lack of adequate testing and validation.

Most Federal agencies have no overall strategy for the development and use of models; consequently many legislative requirements and decisionmaker needs for information are not being met. Due to the newness and technical complexity of the modeling field, **levels of communication between decisionmakers and modelers are low, and little coordination of model development, dissemination, or use occurs *within* individual Federal agencies.** Developers, working either as Federal employees or as private contractors, tend to have a relatively free hand in creating and using models. While the independence afforded to their development has facilitated rapid advances in design, the **lack of accountability has resulted in models that often fail to address decisionmakers' needs for information, require impractical amounts of data, or are not well enough explained to enable others to use them.**

Successful modeling requires adequate resources for support services, such as user assistance, as well as for development. Presently, model development has outstripped corresponding support for models. In the past, model developers have put a premium on developing models, while support for models—documentation, validation, dissemination, user assistance, and maintenance—has been neglected. Often, resources are focused on development, but are unavailable for support activities. The neglect of model support has led to a multiplicity of models, most of which are underutilized. Many of these models cannot be used by personnel other than the developer, due to lack of documentation, access to the model, and user assistance.

Federal agencies that have had considerable success with modeling have devoted substantial attention to the problem-solving needs of potential users and decisionmakers, and to providing adequate support services. These programs generally include a central responsibility for disseminating software and documentation, providing training and technical assistance, and updating and maintaining models.

State governments frequently use water resource models, although many wish to use them more extensively than is currently possible. OTA's survey of State water resources professionals indicates that ***potential* levels of model use at the State level are at least twice as high as *current* use levels.** Technical capabilities at the State level tend to be limited—staffs are small, and prevailing salary scales prevent many States from hiring and/or retaining adequate numbers of personnel with modeling skills. Consequently, **most States depend primarily on the Federal Government to provide them with suitable models, technical expertise, and training in model use.** Those Federal agencies that have had considerable success in assisting States have made substantial commitments to providing support services—USGS runs a cooperative program that currently assists over 600 State and local agencies in developing and applying models, while the Corps of Engineers' Hydrologic Engineering Center (HEC) widely provides services to State and local governments, and assists them in using HEC-built models.

Lack of information is a major barrier to State and local use of models—personnel are often unaware that models for a given type of analysis already exist. Additionally, many federally developed models are inappropriate for use at the State level. The specific needs of States are infrequently considered in Federal model development. Many States reported that their analytic and modeling capabilities must be expanded if States are to assume a larger role in future water resource decisionmaking.

ISSUES

The issues discussed in this section focus on the potential to improve the Federal role in developing, using, and disseminating water resource models. Opportunities for increasing the efficiency and effectiveness of current model-related efforts and programs are noted, although the general nature of the options set forth prohibit development of specific cost estimates or estimates of the potential savings associated with a given option. Each option presented for congressional consideration is designed to increase the productivity of the billions of dollars invested annually in water resources and water resource management. Issues 1 and 3, "Improving Federal Problem-Solving Capabilities," and "Establishing Appropriate Modeling Strategies Within Individual Federal Agencies," are directed toward making more effective use of the approximately $50 million per year spent by the Federal Government on water resource modeling; issues 2, 4, and 5, "Meeting the Needs of the States," "Providing Potential Users With Information About Existing Models," and "Federal Support for Model-Related Training," focus on improving modeling capabilities through the provision of augmented model-related services.

Issue 1: Improving Federal Problem-Solving Capabilities

Many of the analytic responsibilities mandated by Federal and State water resources legislation cannot adequately be carried out without models. However, **the analytic tools needed to fulfill many legislative requirements and decisionmaker information needs are currently unavailable. The majority of Federal agencies have no overall strategy for developing, using, disseminating, and maintaining these tools.** Models tend to be built on an ad hoc basis, in response to immediate problems, rather than as a result of integrated planning. In the absence of any comprehensive model development and support strategy, Federal agencies are often unresponsive to State and Federal problem-solving needs, or to congressional directives expressed in water resources legislation.

The OTA survey of Federal agencies reveals great variation in the use of water resource models. Although a particular law may assign similar analytic responsibilities to a number of agencies, some agencies will employ the most sophisticated computer tools available for their analyses, while others rely primarily on simpler approaches. In some cases, this may be all that is needed; however, in many instances, **implementation of legislative requirements could be improved by more sophisticated Federal analytic capabilities.** While a few agencies are extensively involved in developing modeling expertise (e.g., Corps of Engineers and USGS) most agency modeling efforts vary greatly from issue to issue, from program to program, and from decisionmaker to decisionmaker.

Most water resource problems, and the Federal legislation that deals with them, affect a number of Federal agencies. However, each agency is individually responsible for developing and funding the analytic tools it requires. While many models have widespread potential use among a variety of Federal institutions, it is often impossible for any one agency to commit the personnel and financial resources necessary to bring them to completion. Developing these tools is expensive and technically complex. For example, the problem of collecting enough data to fine-tune models and test their accuracy can inhibit model development by a single agency. **Unless clear direction and priority-setting mechanisms are provided by Congress and the Executive Office of the President, the best analytic tools will not be available throughout the Federal Government, and many needed models will not be built or supported.**

At present, minimal Federal oversight exists for the funding of applied research and development (R&D) activities. The mechanisms that currently exist for coordinating water resources analysis focus almost entirely on research needs. Neither the information required for solving policy problems nor the analytic techniques needed to aid in decisionmaking are directly addressed in the current process for coordinating the Federal R&D agenda in water resources. Under the Water Research and Development Act of 1978, the Secretary of the Interior is presently directed to develop a 5-year water resources research program, drawing on the expertise and advice of appropriate Federal agencies, the State water resources research institutes, and other appropriate entities. The program is to indicate goals, objectives, priorities, and funding recommendations to the President and Congress for water resources R&D. That document is intended to serve as the basis for funding allocations in the budget processes of Congress and the Executive Office of the President.

While the 1978 act recognizes the need to strengthen, "The capability for assessment, planning, and policy-formulation . . . at the Federal and State level," it provides no specific direction to determine what mix of research and problem-solving capabilities can best meet Federal needs. Moreover, **by concentrating primarily on research needs, it misdirects mission agency priorities toward research per se rather than toward coordinated development and utilization of scientific knowledge and related analytic capabilities.** The research focus of the current act also reinforces tendencies within individual agencies to fund projects that reflect the agency's mission, rather than priority problems identified by Congress and the Executive Office of the President.

Options available to Congress include:

OPTION 1-A:

Congress could amend the Water Research and Development Act of 1978 to specify the development of a multiyear plan emphasizing a mix of R&D needs, usable analytic tools, and support services for ensuring that these tools are available to water managers.

Under the act, Congress has directed the Secretary of the Interior to develop a 5-year water resources research program. This mechanism for coordinating Federal efforts to help solve water resource problems might be more effective if a broader range of problem-solving needs were considered.

Over a dozen reports defining Federal water resources research needs have been prepared over the last 20 years.[10] The latest of these, the National Research Council review of the draft Five-Year Plan specified by the act, lists major water resource problems, and further states that:

> For many of the foregoing problems the basic and applied research has already been accomplished in substantial part, if not entirely. What is often lacking, however, is adequate technology transfer . . . Solution of many other problems requires research and development to advance the state of knowledge.

The individual agency research plans submitted for use in developing the Five-Year Plan gave high priority to the development of mathematical models. Similarly, a 1977 report on research needs by the Committee on Water Resources Research stated that, "Throughout this 'catalog of needed research,' there is a strong theme that calls for continually improving mathematical and physical modeling capability."[11]

As with previous plans, the latest Five-Year Plan proposal has not been as effective as it might have been, due to its emphasis on a research agenda. While models have been acknowledged as important *research* tools, little attention has been paid to developing the analytic tools and support capability needed to meet Federal and non-Federal water resource problem-solving responsibilities. Major gains in the effectiveness of Federal modeling efforts can be achieved through systematic provision of such support services as assistance in locating and obtaining usable existing models, testing and evaluating models for application to different conditions and decisionmaking needs, and training and technical assistance in using the models.

Mathematical models are an important component of the water resource analysis needs of Federal agencies. However, as with other forms of R&D, creating these tools is only the first step in establishing needed analytic capabilities. Congress could expand the scope of the Water Research and Development Act to specifically address a broader range of analytic and problem-solving needs for water resources decisionmaking, and provide a mechanism (such as an interagency coordinating committee) to carry out the intent of the act.

OPTION 1-B:

Congress could establish an interagency unit whose responsibilities include developing a multiyear plan for water resource analytical needs and coordinating the implementation of the plan.

Interagency representation may be necessary for successful coordination. This unit might be housed either within the Office of Science and Technology Policy or in an interagency water resources policy organization similar to the Water Resources Council or its potential successor. The unit might be directed to work closely with the Office of Management and Budget for budgetary review.

OPTION 1-C:

When addressing priority problems through legislation, Congress could establish specific mechanisms to provide adequate Federal water resource analytic capabilities to meet the intent of the legislation.

Congress could explicitly direct Federal agencies to provide institutional support for the analytic capabilities needed to implement legislative goals. A number of approaches could be used for providing these capabilities, including centers of excellence at universities, operating units within existing Government organizations, and agency and interagency demonstration programs for creating support units. Examples of such support units as the Fish and Wildlife Service Instream Flow Group are described in chapter 4.

Issue 2: Meeting the Needs of the States

Most of the Nation's major water resource legislation is based on the concept of a strong State-Federal partnership for managing and planning the use and protection of the Nation's water. **If States are to fulfill their responsibilities, and take on an increasing share of water resource management delegations in the future, it is in the Nation's best interest to ensure that the States have ac-**

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[10] *Federal Water Resources: A Review of the Proposed Five-Year Program Plan*, Water Resources Research Review Committee, Commission on National Resources, National Research Council: National Academy Press, 1981.

[11] *Directions in U.S. Water Research: 1978-1982*, Committee on Water Resources Research of the Federal Coordinating Council for Science, Engineering, and Technology (Springfield, Va.: National Technical Information Service PB 274 278, October 1977).

cess to, and are capable of using, the best available analytic tools.

Many States depend heavily on Federal agencies for assistance in modeling, and rely primarily on models that: 1) are widely available, 2) have a long history of use, and 3) are well supported by Federal agencies. Most States lack the financial resources and the technical expertise required to develop models independently. States frequently share common responsibilities or problems, and can take advantage of federally developed models designed for application to a wide variety of natural, social, and economic situations. Even for situations where differences among States require substantially different models, agencies of the Federal Government are important centers of expertise to which States turn for modeling assistance.

However, many of the models that Federal agencies routinely use are inappropriate to assist the States in fulfilling their water resources responsibilities. Even when agencies develop models that relate to State concerns, they often have no mandate to assist the States in analyzing their water resource problems. Consequently, many States find that such models are too complex to use, require more input data than States can afford to collect, or fail to meet specific State analytical needs.

Although a few agencies, such as EPA, solicit general input from the States through advisory panels or other means, **State needs are largely neglected in Federal agency modeling processes. If State agencies are to utilize Federal models to a greater extent, practical mechanisms must be devised for providing State input into the model development processes within individual Federal agencies.**

In addition, for the Federal Government to be effective in assisting States to analyze water resource issues, it must first develop reliable means of obtaining information about State needs. Mechanisms for assuring State input into Federal R&D processes, as specified under the Water Research and Development Act of 1978, are inadequate. The current act directs the 54 State (and territorial) water resources research institutes to develop 5-year research program reports in close consultation with appropriate State agencies, and to submit these to the Secretary of the Interior for use in developing a 5-year coordinated Federal water resources research program. As outlined in Issue 1, "Improving Federal Problem-Solving Capabilities," such a procedure focuses primarily on water resources research, and does not give adequate consideration to developing and supporting analytic tools for solving important water resource problems. In addition, it makes the State water resources research institutes the primary liaisons between the States and Federal water resource planning. The institutes, many of which were created by Federal legislation and operate primarily through Federal funding, are primarily research centers.

The capacities and functions of the State water research institutes vary widely. Some compete extensively for discretionary Federal research funding, while others operate primarily on the small basic allocation provided to all 54 institutions. Some are actively involved in pursuing solutions to water resource problems that affect their States, while others concentrate on scientific problems that may have few near-term practical ramifications.

Perhaps most importantly, the institutes have a federally authorized research focus that makes it difficult for them to adequately account for the applied research and problem-solving needs of State and local water resources agencies. While they play a vitally important role in the long-term development of expertise, the institutes are in a relatively weak position to voice State agency needs to the Federal Government.

Two additional pressing needs identified in the OTA survey of State water resource agencies are discussed in detail under issues 4 and 5: 1) better access to information about existing models; and 2) increased training opportunities in model use for State personnel.

Options available to Congress include:

OPTION 2-A:

Congress could direct the States to designate a lead State agency to assist the Secretary of the Interior, or other designee, in developing a multiyear plan for water resource analysis needs.

The Water Research and Development Act directs the State water resources research institutes, in consultation with State agencies, to provide input to the Five-Year Plan mandated by the act. If the Federal Government is to assist States in meeting water-related responsibilities, it must take into account a wide range of State water resource agency information and analytic needs. Congress could amend the act to allow the States to designate a lead State agency or a water resources research institute to participate in planning a broader multiyear Federal agenda.

OPTION 2-B:

Congress could strengthen the States' own capabilities to undertake sophisticated water resource analysis.

As the States' water resource management responsibilities have increased, so have the States' requirements for sophisticated water resource analysis. Improving the States' own analytic capabilities, either through federally sponsored training or by funding the States to develop and use their own analytic tools, could allow States to be less dependent on Federal agencies for analysis.

For example, the Clean Water Act (Public Law 95-217) directs the Administrator of EPA to make grants to planning agencies to develop a comprehensive water quality control plan for a river basin. Congress might consider similar programs for water resource development programs. If the States are to assume a greater role in the priority-setting process, Congress might consider including formula funding to strengthen States' analytic capabilities.

OPTION 2-C:

Congress could direct Federal water resource agencies to respond to the analytical needs of the States whenever States are to implement Federal programs.

For example, under the Safe Drinking Water Act, the States have primary enforcement responsibility for public water systems. The act specifically directs the Administrator of EPA to conduct research and demonstrations of "improved methods (i) to identify and measure the existence of contaminants in drinking water (including methods which may be used by State and local health and water officials), and (ii) to identify the source of such contaminants." One activity undertaken by EPA--funding the Holcomb Ground Water Model Clearinghouse—helps the States obtain ground water quality models used to identify the transport and fate of pollutants.

Photo credit: © Ted Spiegel, 1982

Toxic wastes from dump sites can migrate into ground and surface waters, contaminating public and private water supplies, and endangering aquatic and other wildlife. Models of contaminant transport, although still in early stages of development, are useful in estimating the spread of contaminants from improper disposal sites, and in designing new landfills to minimize leakage of toxic materials

Congress could direct Federal agencies to establish similar mechanisms to assist the States whenever Federal programs are to be implemented by the States, and ensure, through its oversight responsibility, that these programs are adequate.

Issue 3: Establishing Appropriate Modeling Strategies Within Individual Federal Agencies

Many of the major Federal water resource agencies lack an integrated plan for developing and supporting models. These agencies generally develop models in response to an immediate need to solve particular problems. Few attempts have been made to integrate related modeling efforts within each agency. Moreover, many models are produced without serious attention to decisionmakers' needs or significant managerial input. Models may not have been tested to determine their ranges of error and applicability to different conditions, and model assumptions and results may not be explained well enough to allow decisionmakers to interpret them properly. Consequently, some agencies may have a multiplicity of models, only a few of which are actually usable.

A few Federal agencies or offices, however, have established comprehensive strategies for developing and supporting models. These strategies generally take two different forms: 1) developing the capacity to analyze priority water resource problems encountered by many users, through a limited number of carefully selected models; or 2) developing a general capability for analyzing individual problems on a one-time or limited basis. Each involves different mixes of model development and support activities.

Outstanding examples of both modeling approaches currently exist within the Federal Government. The Hydrologic Engineering Center (HEC) has extensively developed the capacity to maintain and support 12 Corps-built models. HEC support services include training in model use and technical assistance to users. EPA, upon the completion of its Stormwater Management Model (SWMM), established the SWMM Users' Group to encourage the model's dissemination and use. Since its inception in 1973, membership has grown to over 500 users, who meet to exchange information and ideas relating to the model's use, assist each other in running it, and explore alternative analytic tools. A description of HEC and SWMM User Group activities is provided in chapter 4 of this report.

Developing selective modeling capabilities can be an effective strategy when frequently occurring priority problems appear to be solvable with some kind of standard technique. Models for dealing with these problems are generally developed in anticipation of repeated application by a variety of users. Their design must give close attention to user needs and capabilities. Models must be thoroughly explained, or *documented,* tested for use over a wide variety of conditions, easily accessible, and usable on many different computer facilities without major modifications.

To assure that the models are widely and appropriately used, the sponsoring agency must further develop a coordinated program of user support services, including: 1) training programs—with "hands-on" instruction, if possible; 2) one-on-one technical assistance, for problems that arise in the course of running the model and interpreting its results; and 3) model maintenance, to incorporate improvements and assure that users are informed of such modifications.

Agency expenditures in support of such a program need not be large. Services for frequently used models are often provided by the private sector on a paid consultant basis. Agencies may need only to provide rudimentary services, directing users to appropriate sources of further assistance. However, the agency would need to ensure that the necessary support is available and of the highest quality.

More general modeling capabilities have been developed by USGS, which maintains a cooperative assistance program that provides services on a cost-sharing basis to over 600 State and local agencies. To meet the requirements of these dispersed users, USGS maintains numerous models that can be adapted by its staff to specific local situations. USGS model-related activities are described in detail in chapter 4 of this report. The diversity of user needs, particularly for ground water modeling, makes this approach particularly helpful for assisting non-Federal agencies lacking inhouse modeling capabilities.

For users with unique information and analytic needs, developing standard models to anticipate such needs may be inappropriate. In these situations, strategies emphasizing general modeling capabilities, which stand in readiness to produce or adapt a model appropriate to each user's particular needs, may be more effective. Such a strategy requires personnel capable of routinely coordinating model development, bringing scientific knowledge and modeling expertise to bear on unique situations. While the individual models require appropriate support (e.g., adequate testing and documentation), the process focuses on the needs of a single decisionmaker or decisionmaking group, rather than on those of many dispersed users. Developers must work closely with the user to adapt the model to the particular issue, test and apply the model, and interpret its results.

Developing comprehensive strategies for building and disseminating water resource models is a pressing need for each of the Federal agencies involved in this field. Decisions on what kinds of modeling capabilities to develop, and what levels of funding to allocate in support of them, need to be made at top policymaking levels within each agency for the agency as a whole, taking into consideration its present and future responsibilities, and its role in providing other Federal, State, and local government entities with assistance in model use. While issue 1 addressed strategies for improving interagency coordination of water resource modeling activities, long-range intra-agency planning for the models and related support services within each agency's purview must supplement interagency coordination efforts.

An option available to Congress includes:

OPTION 3-A:

> **Congress could, through its oversight responsibilities, direct each of the major Federal water resource agencies to develop a coordinated strategy for the development, dissemination, and use of models.**

OTA case studies indicate that coordinated planning is necessary for providing effective institutional support to encourage model development, dissemination, and use. While the approaches used in existing programs differ widely, successful efforts have two elements in common: 1) the models are of high quality, have been evaluated over a wide range of conditions, and are responsive to users' needs; and 2) the models are well documented and maintained, easily accessible, and are associated with adequate technical assistance. Oversight activities to ensure the development of a strategy incorporating each of these elements could help promote a more effective problem-solving capability within Federal agencies.

Two elements that are integral to the development of comprehensive modeling strategies—training and the availability of information about models—are discussed below as issues 4 and 5.

Issue 4: Providing Potential Users With Information About Existing Models

Many models currently developed by Federal agencies are intended for a single application—once they have been built, and are used to analyze a single problem, they are considered to have served their purpose, and are shelved. Since they are not designed for distribution, information on their existence is not typically made available outside the agency. Consequently, other agencies with potential uses for these models may be unaware that such models even exist. Often the models are not tested to determine their accuracy and applicability to other situations, nor are they sufficiently documented so that others may choose to use them. Models developed by outside contractors, but which are left undocumented or are documented inadequately, may not even be usable by other personnel within the same agency.

No entity within the Federal Government is specifically charged with providing information to potential users—Federal or non-Federal—about the governmentwide availability of water resource models. Three existing units provide such information as part of a more general mission; each, however, is limited in its ability to gather comprehensive information on existing Federal models, rapidly access that information for users, and match user needs to available models.

The Water Resources Scientific Information Center (WRSIC) has supported two major sources of water resource information, *Selected Water Resources Abstracts,* and the Water Resources Research in Progress File. Both have provided reference services geared to trained water resource professionals—information on modeling activities is included, but not in a format that allows for ready access to specific types of models. Moreover, the services do not reference models or documentation directly. They can at most identify publications in which models are cited or described, or ongoing research projects that involve modeling activities. Recent cost-saving initiatives are projected to substantially curtail WRSIC activities, particularly in the area of printed material; however, computer-based information retrieval services for accessing published work are expected to be maintained.

The National Technical Information Service (NTIS) collects and sells data files, computer programs, and model documentation manuals from Federal sources. The sheer magnitude of the NTIS mission—responsibility for disseminating over 1 million publications—makes it extremely difficult for NTIS to provide detailed assistance to potential computer model users. Its information retrieval system is not well suited for locating available computer tapes of models. Recently, NTIS files of computer tapes have been combined with those of the General Services Administration's Federal Software Exchange Center (FSEC).

FSEC serves as a central repository for computer programs that Federal agencies consider to be widely applicable. Its holdings span an extremely wide range of subjects, and water resource models comprise only a small portion of the available software. Since FSEC has a very limited staff, it cannot assist users in determining the capabilities and limitations of its models, running them, or interpreting results. Moreover, agencies provide models to the Center on a purely voluntary basis, and FSEC regulations prohibit the Center from identifying the agency that developed the model to potential users without the agency's expressed consent. Lacking access to the individuals who developed the model, users may have difficulty in applying it to the problems they need to analyze. The organization's inability to provide user support limits its primary utility to professionals with highly developed modeling expertise.

All of these organizations provide information on models that have been documented and supplied to them by various Federal agencies. However, many Federal models are not entered into any of these systems, and many that have been entered have been inadequately documented.

A number of attempts have also been made at agency levels to provide relatively detailed information on models dealing with specific subject areas. Two of the larger systems dealing with water resource concerns are the Department of Agriculture's Land and Water Resources and Economic Modeling System, and the EPA Center for Water Quality Modeling, both of which are described in detail in chapter 4 of this report.

In recent years, the concept of a model *clearinghouse* has gained many adherents in the scientific and managerial community. **Such clearinghouses would be designed to organize models for easy access by users with specific analytical needs.** To test the utility of the clearinghouse approach, EPA has sponsored the development of the International Clearinghouse for Ground Water Models (ICGWM) at the Holcomb Research Institute. An extensive description of ICGWM is provided in chapter 4 of this report. Preliminary findings indicate that ICGWM has been very successful in improving the accessibility of ground water models. Clearinghouses, however, remain a controversial approach. Some water resources professionals are skeptical of their cost effectiveness, and of any one organization's ability to provide expertise about large numbers of mathematical models.

Options available to Congress include:

OPTION 4-A:

Congress could direct the Federal water resource agencies to make information on agency models available to outside users and to establish mechanisms to distribute these models on request.

Several water resource agencies have already established catalogs of existing models, but on the whole, it is extremely difficult to obtain information about the existence and specifications of federally developed models. This information is generally unavailable to potential users in local, State, or other Federal agencies.

A second component of information transfer is the dissemination of the computer program for the model. Such programs are also generally difficult to obtain. One office with extensive capabilities for distributing models to potential users is HEC, described in chapter 4. Congress could direct agencies that do not presently distribute the results of federally funded modeling activities to do so at reasonable cost to the user.

OPTION 4-B:

Congress could expand the role of existing information transfer agencies to be more responsive to the modeling information needs of water managers, and encourage water resource agencies to use these existing mechanisms.

Either FSEC or WRSIC could be expanded to serve as a Federal Government-wide repository of water resource models and model information. Each of these groups currently provides limited information about water resource models—FSEC focuses directly on models, but has no water resource-related mission or expertise, while WRSIC is a comprehensive information source for water resource research, with no model-related mission or expertise. Neither provides the support services required for assisting potential model users.

Water resource agencies would have to be encouraged to assist the chosen information transfer agency in expanding its services.

OPTION 4-C:

Congress could establish a national clearinghouse system for the distribution of water resource models.

Though several model clearinghouses currently exist in the United States, many important water modeling areas are not covered by any existing organization. The Holcomb Clearinghouse contains an extensive file of ground water models, and EPA's newly established Center for Water Quality Modeling contains information on a few of the most popular surface water quality models.

Due to the substantial interconnections and overlaps among water resource modeling activities, many professionals consider it desirable to develop a comprehensive center to which a water resource manager could turn to obtain complete information on the availability of models. Such a center would bring together models developed by the Federal Government, States, and the private sector. A centralized clearinghouse, or a series of clearinghouses, containing information on models of all aspects of water resources—quality and quantity of both ground and surface waters, as well as the social and economic implications of water use—could assist water managers to choose amongst the multitude of available tools.

''Seed money'' would be required to start a national clearinghouse, but after several years of operation, equitably designed user fees could cover a substantial portion of clearinghouse operation costs. The clearinghouse should provide, at a minimum, information about available models. Additional services could include providing computer programs, or more extensive services such as training courses.

OPTION 4-D:

Congress could fund an interagency demonstration project to evaluate and compare existing models for a representative range of field conditions.

Though thousands of water resource models are currently available, few have been evaluated for conditions other than those under which they were developed. Information about the accuracy of models is difficult to obtain—and for many models is nonexistent. Poor validation of models is a major complaint of potential users and a significant constraint on model use.

For common types of analyses, such as projecting water quality changes from a proposed sewage treatment plant, Congress could direct the appropriate agencies to choose several models, evaluate them under a wide range of conditions, and compare their strengths and weaknesses for different purposes. Because of the benefits that such an evaluation would provide to the professional water resource community, professional societies might be willing to jointly undertake the project. The results of these evaluations would assist professionals in choosing tools appropriate to their needs, and give decisionmakers greater confidence in the results.

If the demonstration program is successful, a more formal mechanism for interagency model evaluation might be established.

Issue 5: Federal Support for Model-Related Training

Federal funding currently provides much of the support for training personnel to develop, use, and interpret water resource models. However, **Federal, State, and private sector personnel reported that the inadequacy of current levels of model-**

related training is a major impediment to meeting the needs of local, State, and Federal agencies. State water resource professionals considered increased federally sponsored training opportunities to be a top priority. In addition, officials of Federal agencies that sponsor training programs acknowledge that inadequate resources are presently provided for training nonagency personnel, and that current agency training opportunities fall far short of demand. If models are to be used effectively in water resource analysis, training in basic concepts of modeling and in proper interpretation of model results must be offered to decisionmakers at all levels of government. Finally, Federal support for the academic training of future water resource professionals has been threatened by recent cost-saving initiatives.

There are three major aspects to model-related training: 1) general educational opportunities in water resources research and analysis; 2) specific training in the use of individual water resource models; and 3) continuing education for manager/decisionmakers and users. Each involves a different kind of Federal training support.

Educating water resources professionals involves extensive academic training, and requires support for research and related overhead. Since 1965, the Office of Water Research and Technology (OWRT) of the Department of Interior has sponsored the University Water Research Program. The program provides seed money, through the State water resources research institutes, for training students in water-related studies and providing equipment for student and faculty research work. Individuals who benefit from the program may become model developers, or water resources managers, or analysts who use water resource models. Federal expenditures for the program amounted to approximately $11 million for fiscal year 1980. Funding has been provided on a matching basis

Photo credit: © Ted Spiegel, 1982

A hydrologist at USGS headquarters in Reston, Va., instructs staff in the use of one of the agency's streamflow models at a desktop computer terminal with State governments, which contributed over $17 million to the institutes during the same fiscal year. Over the past 16 years, the program has made a significant contribution to alleviating the shortage of qualified technical manpower for water resource management. Federal appropriations for the University Water Research Program for fiscal year 1982 have been reduced to approximately $6 million. The fate of the University Water Research Program is still uncertain. OWRT has been scheduled for elimination, with its responsibilities to be transferred to other offices and programs, before the end of the current fiscal year.

Model users require specific training to enable them to use a particular model and apply it to actual problems. Such training is a critical component in transferring modeling technologies from the developer to the organizations charged with solving water resource problems. Many models go unused, or are underused, because such training is not widely available. USGS and HEC are among the Federal agencies that presently conduct training courses in model use—HEC training courses reserve approximately 10 percent of classroom places for State and non-Corps of Engineers Federal personnel in 24 weeks of formal training programs per year. These courses have greatly expanded the use of HEC and USGS models, and improved the proficiency of water resource professionals in using them. While both agencies strongly support the concept of one-on-one training and "hands-on" workshops in model use, the cost involved in providing these forms of training limit their present use. Using a different approach from that of HEC, the SWMM User's Group provides such assistance informally, or on a fee basis among members. Use of the SWMM model has become so widespread that a number of universities around the country have begun to provide training courses in its use; EPA has not been obliged to provide formal training instruction since the fall of 1976.

Short training courses in a number of the more widely used models are available through public and private universities. These courses are highly valuable in providing users with the information necessary to operate models and interpret their results.

Managers and decisionmakers are often unprepared for the problems and complications associated with model use for water resource problems. Many have completed their formal education prior to the widespread use of computer modeling techniques, and do not understand the concepts underlying computer-based simulation and analysis. **Few Federal agencies have yet made a significant commitment to decisionmaker education and retraining to accommodate modeling techniques.** The Instream Flow Group currently conducts an executive training program to enable field personnel and administrators to use model-based recommendations; ICGWM has recently begun a series of ground water modeling workshops, the most introductory of which discusses the application and limitations of models for policymakers and decisionmakers. Nonetheless, Federal efforts to provide continuing education in model use for management-level personnel are still in very early stages.

Options available to Congress include:

OPTION 5-A:

Congress could allocate resources to water resource agencies specifically for establishing inhouse and extramural training programs for their personnel, and for water managers in State and local agencies.

Two types of training programs are needed: 1) courses on the use of specific models for potential model users; and 2) continuing education for managers and decisionmakers to understand the strengths and weaknesses of model-based analyses.

Several examples of training programs are described in chapter 4. These range from courses offered by HEC to the informal conferences of SWMM's Model User's Group. While excellent examples of training programs exist for agencies to follow, the need for additional programs is great.

A variety of approaches could be used for developing adequate training programs. Agencies could arrange to fund training provided by universities with acknowledged expertise in water resource modeling, or develop inhouse training capabilities through agency personnel or outside contractors.

OPTION 5-B:

Congress could expand the current programs assisting university-level water resources education.

Training grants to universities, and research grants that provide the opportunity for students to obtain experience in analyzing water resource problems, are two mechanisms by which Congress can help provide an adequate supply of well-trained professionals.

Educating students in state-of-the-art analysis techniques, often available at universities throughout the country but not within Federal, State, and local agencies, brings these techniques to the agencies when these students graduate and are hired. Research and training programs offered through the National Science Foundation and OWRT are important mechanisms for meeting future agency-level analytical needs.

Chapter 2

Introduction to Water Resource Models

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Chapter 2

Introduction to Water Resource Models

INTRODUCTION

The Nation's water resource policies affect many domestic problems in the United States today—energy, the environment, food production, regional economic development, and even the international balance of trade. As the country grows, excess water supplies diminish, and it becomes increasingly important to manage existing supplies with the greatest possible efficiency. Americans are demanding more water—and cleaner water—for households, industry, agriculture, energy development, recreational use, and aquatic life. For many areas of the country, the availability of adequate water supplies is a limiting factor in residential construction, agricultural production, and economic development in general.

As the Nation approaches full utilization of its water resources, water resource management is becoming more complex. Different kinds of uses, and user groups, increasingly compete for limited supplies. Moreover, interconnections among virtually all aspects of water systems are increasingly apparent—streamflows affect underground reservoirs, for example, while manmade civil works, laws, and regulations have profound consequences for the hydrologic balances of entire regions.

Thus, the ability to manage and plan the use of America's water resources—and determine the consequences of resource decisionmaking—becomes increasingly important and increasingly difficult as well. In recent years, successful management and planning has increasingly been based on the results of mathematical models. The information provided by these tools is used to help make such decisions as funding flood control structures, planning pollution control programs, or operating water supply reservoirs.

Leaving aside the mystique of computers and complex mathematics, mathematical models are simply tools used to help understand water resources and water resource management activities. Before the dams and sewage treatment plants are built, before actions are taken to comply with regulations, problems must be analyzed to determine an appropriate way to proceed.

This part of water resource management, though not as apparent as the reservoirs, pipes and sewers, is a vital component in meeting the Nation's water resource needs. As the desire for more and cleaner water grows, careful analysis becomes more important. Today, wasting water reduces the amounts available for others. Over-building dams or sewage treatment plants wastes money that could be available for other purposes.

Sophisticated analysis, through the use of models, can improve our understanding of water resources and water resource activities, and help prevent wasting both water and money.

This assessment of water resource models is therefore not an assessment of mathematical equations or computers, but of the Nation's ability to use models to more efficiently and effectively analyze and solve water resource problems. The assessment considers not only the usefulness of the technology—the models—but the ability of Federal and State water resource agencies to effectively use these analytic tools.

Models have been available to assist water resources management, planning, and policy for several decades. In 1959, the former Senate Select Committee on National Water Resources made one of the earliest uses of models for policy purposes. The committee investigated the importance of water resources to the national interest, and considered the Federal activities required to provide the desired quantity and quality of water. To aid in its investigations, the committee called on Resources for the Future to develop a model of water supply and projected use for 1980 and 2000.[1]

During the 1950's and early 1960's, many water resource professionals began to realize the potential of models for improving management and planning—but were overly optimistic about the ease with which these tools could be developed and adopted for general use. During the 1970's, as computers became more readily available and the cost of computation decreased, model development flourished. However, as often occurs, the technology outstripped the capability of the institutions—the State and Federal agencies—to support it. Today, model use is increasing the efficiency and lowering the cost of water resource management, but the potential for further improvement remains great.

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[1] U.S. Senate Select Committee on National Water Resources, Committee Print No. 32. (Washington, D.C.: U.S. Government Printing Office, 1960).

The following section of this chapter outlines the basic principles and functions of water resource models, and briefly describes the major types and classifications of the models. A further section introduces the 33 major water resource issues (table 1) for which model use was analyzed and surveyed. The chapter concludes with a case study that illustrates how models were used to deal with a variety of water resource problems in the Riverhead-Peconic area of Long Island, N.Y.

Table 1.—Specific Water Resource Issues Addressed in Report

Surface water flow and supply

- Hydrology:
  - Flood forecasting and control
  - Drought and low-flow river forecasting
  - Streamflow regulation (including reservoirs)
  - Instream flow needs (fish and wildlife, recreation, hydroelectricity, etc.
- Use:
  - Domestic water supply
  - Irrigated agriculture
  - Offstream use (other than domestic and agriculture)
  - Water use efficiency and conservation

Surface water quality

- Nonpoint source pollution and land use:
  - Urban runoff
  - Erosion and sedimentation
  - Salinity
  - Agricultural runoff (other than erosion and salinity)
  - Airborne pollutants
- Water quality (other than nonpoint source and land use):
  - Wasteload allocation (point source discharges)
  - Thermal pollution
  - Toxic materials
  - Drinking water quality
  - Water quality impacts on aquatic life (including eutrophication)

Ground water—quality and quantity

- Quantity:
  - Available supplies and safe yields
  - Conjunctive use of ground and surface waters
- Quality:
  - Accidental (and preexisting) contamination of ground water for drinking water (including toxic substances)
  - Agricultural pollutants to ground water
  - Movement of pollutants into and through ground waters from waste disposal (landfill siting, injection, etc.)
  - Saltwater intrusion

Economic and social

- Economic:
  - Effects of water pricing on use
  - Economic costs of pollution control by industrial sector
  - Benefit/cost analysis
  - Regional economic development implications of water resource policy
- Social and integrative:
  - Forecasting water use
  - Social impact analysis
  - Risk/benefit analysis
  - Competitive water use demands (by region, by sector and water quality objectives
  - Unified river basin planning and management

SOURCE: Office of Technology Assessment.

INTRODUCTION TO WATER RESOURCE MODELS

What are water resource models? Briefly, they are analytical tools used to determine the consequences of proposed actions or forecast the quantity or quality of the water in the Nation's rivers, lakes, or ground waters. These models, which range in sophistication from simple work with a desk calculator to complex computer programs, are the scientific community's way of understanding and predicting the workings of a water system. Models are used to synthesize and analyze the substantial amounts of water quality, quantity, and societal information needed for effective planning and management. Effective models condense large amounts of data, simulate the physical and biological dynamics within a water body, or suggest solutions that are most equitable to competing water users.

A model is a "numerical representation" of how the real world or some part of it—a lake, a dam, or a community—works. More precisely, a model uses numbers or symbols to represent *relationships* among the *components* of these real-world systems. A river basin, for example, is composed of water flowing in natural (and manmade) channels, and may have dams that generate electricity and create water impoundments. The river's waters are often used by domestic, industrial, and agricultural consumers within the basin. The basin normally contains a wide variety of aquatic and related wildlife, and may attract numerous users of recreation and recreational facilities. All of these may be considered components of a river basin system; if they can be meaningfully quantified, they can be included in a mathematical representation, or model, of the river basin.

Models deal with the interrelationships among the components of a system. For example, the decision to store water behind a dam will increase (or maintain) the size of a lake behind the dam, and decrease the amount of water flowing below the dam and the amount of electricity generated at the site. The action may increase the number of fish in the lake, attracting more fishing enthusiasts, and reduce the level of water in a marsh downstream, inducing birds and other wildlife to migrate elsewhere. Models are simply series of equations that express such relationships in mathematical form.

Photo credit: © Ted Spiegel, 1982

In addition to generating hydropower, this dam helps to control streamflow on the lower reaches of the river, and assure adequate water supplies in time of drought. Achieving the multiple objectives involved in reservoir management can be significantly improved and simplified through the use of management-related mathematical models

To take the illustration a step further, if a model accurately represents a system, it can be highly useful in analyzing conflicts among different objectives for managing that system, or ways in which management objectives are complementary. For ensuring adequate water supplies in times of drought, reservoirs must retain as much water as possible. But to control floods, unused storage capacities of reservoirs must be available to receive excess flows. Mathematical expressions are used to represent the quantity of flood waters that can be stored when a given amount of water is being held in reserve for water supplies.

A model is necessarily a simplification of the system it describes. It would not be possible to construct a model that accounted for all the minute interactions of a complex system—but perhaps more important, it would not be useful to do so, either. A model's value as an analytical tool lies in its ability to reduce the number of factors to be considered to a manageable size, selecting the most significant interactions in a system, and assuming that other factors have negligible effects.

Models of how pollutants are transported in a river are good examples of the need for simplifying assumptions. In reality, the flow of a river is three dimensional—the river moves and pollutants are dispersed in all directions. It is often prohibitively complex to represent three-dimensional pollutant transport, however; most river models are designed to describe the transport of pollutants in only one direction—downstream—and ignore vertical or across-channel flow. For purposes of predicting the concentration of pollutants at a location far downstream, i.e., at a drinking water intake pipe, at a specific time, these influences on pollutant transport are negligible.

To determine if model assumptions—like those made for pollutant transport—are valid, model results are tested against actual measurements. For example, if the model's forecast of the time of arrival and the concentration of pollutants at the downstream intake pipe is close to the concentration actually measured at that time, it would appear that it is valid to make these assumptions, at least under these conditions. Usually, in *validating* a model, as this process is called, the model is compared with actual measurements under a variety of conditions.

If a model is found to be a reasonable representation of the real system, it can serve a number of functions. First, it can be used *descriptively* to aid analysts in understanding how the real system works. By way of illustration, when a landfill leaks pollutants into ground water reserves, a model can be used to show how far the contamination has spread, and to estimate pollution levels in a given area. Since these factors can only be *measured* by time-consuming drilling of test wells, the model provides the quickest indication of the extent and seriousness of the problem. The insights gained from the model can then be used to determine the probable location of the most contaminated sites, so that detailed field calculations can be made in those areas.

Models can also be used as *predictive* tools. In a river, for instance, dissolved oxygen levels depend to a large degree on levels of bacterial activity, because as organic matter bacterially decomposes, the bacteria consume dissolved oxygen. Dissolved oxygen concentrations also depend on the exchange of oxygen between the river and the atmosphere, algal photosynthesis and respiration, temperature, sunlight, and many other interactions. Experiments to determine the direct effects of pollution on dissolved oxygen levels would require inducing many different levels of pollution into the river, attempting to keep all the other factors constant, and measuring the result. The experiment would be time-consuming, costly, and difficult to control; moreover, it may be highly undesirable to run such an experiment in the real world. Because equations that represent the major factors in determining oxygen levels can be easily manipulated, models can predict the direct effects of various pollution levels. These models can be used to determine what levels of sewage treatment will be necessary for meeting water quality standards *before* a sewage treatment plant is built.

Often, however, it is not sufficient to predict the consequences of a single event or series of actions. Preventing floods on a river system, for example, involves opening the floodgates of a dam to a particular position in order to release the greatest possible amount of water without flooding downstream areas. Yet if a river system had 10 floodgates, and each floodgate had only 10 positions, a river manager would be faced with 10 billion (10^{10}) possible choices (or combinations) of floodgate settings to choose from in the event of a flood. Assuming that a computer model can predict the amount of water that will be released by a particular combination, and the impact of the release downstream, in about half a minute, evaluating all the possible floodgate settings would require approximately 10,000 years. However, models can also be designed as *optimizing* tools that use mathematical logic to determine the best available choice of settings that satisfies the requirements.

The models analyzed in this report address a wide range of water-related issues. These issues can be organized into four broad categories: surface water flow and supply, surface water quality, ground water quality and quantity, and economic and social.

The category of *surface water flow and supply* includes surface hydrology and water use. Hydrology refers to physical factors that influence the movement of water in rivers and streams. Use, in this case, means water that is withdrawn from a stream for a specific purpose.

Surface water quality issues are divided into point sources (e.g., discharges from a factory) and nonpoint sources (e.g., agricultural runoff).

The third category contains issues pertaining to *ground water,* including available supply and quality with respect to intended use. Also included in this grouping are factors relating to the possible interactions between ground and surface water resources.

Economic, social, and interrelated factors fall into the fourth and final category. Included are the economic and/or social factors that might influence, either directly or indirectly, the availability, quality, or demand for water resources.

In further categorizing models, it is often useful to distinguish between two major benefits that models can provide: 1) delivering information more efficiently than was previously possible; and 2) integrating data to create information that would not otherwise be available. Models that perform the first function rely on established methodologies (e.g., traditional engineering formulae) but use the computer to speed calculation. Models that produce otherwise unavailable information incorporate methodologies that require computer assistance for their execution.

Water resources models can also be characterized by the purpose for which they are used. These include: 1) operations and management; 2) planning; 3) policy development; 4) regulation; and 5) data management.

Models for *operations and management* are used to support short-term managerial decisions. These models might be used to control the operation of a sewage treatment plant or to regulate waterflows through a system of reservoirs within a river basin.

Models that support *planning activities* are often broader in scope than operations and management models, as they are used as an aid to medium-range decisionmaking. Planning models might be used to evaluate alternatives for future expansion of a treatment plant or to study the impact of the proposed development of a water-consuming industry along a river or stream.

Models used for long-range planning would fall under the class of *policy development* models. Policy models might be used to estimate the effects of energy development on western U.S. water resources.

Models for regulation are those used in direct support of enforcement or promulgation of standards or in the issuance of permits. For example, a regulation model might be used to determine the allowable discharge level for a sewage treatment facility prior to the issuance of a permit for facility expansion.

Some models are developed solely for *data management*—organizing and accessing data. These models usually are supported by extensive monitoring and reporting networks, and may include data for a wide range of water-related issues.

Yet another method to classify models is by their technical characteristics. Two of the technical categories most germane to this report are: 1) prescriptive v. descriptive models; and 2) deterministic v. probabilistic models.

Descriptive, or simulation, models "describe" how a system operates, and are used to determine changes resulting from a specific course of action.

They are often used to test alternative plans until a satisfactory option is found.

Prescriptive, or optimization, models, on the other hand, "prescribe" a course of action that best meets a specified objective (e.g., least cost or greatest water yield). If more than one objective is specified, these models can be used to describe the tradeoffs among best solutions for the various objectives.

In *deterministic* models, the results of an event or series of events are given as a single number or data series, without indication of extent of possible error in the resulting calculations. The quantitative relationships among the parts of the system are fixed—results are completely "determined" by the model and the data provided.

Probabilistic, or stochastic, models produce data that are expressed as a range of probable results. Such models take into account the fact that many events appear to occur randomly. For example, the intensity and timing of any particular rainfall event cannot be precisely predicted, but must be described as a probability of occurrence.

WATER RESOURCE ISSUES

A broad spectrum of activities is involved in managing water resources. Networks for receiving, routing, and using rainfall—both manmade facilities and alterations to natural systems—must be planned, built, and operated. The quality of various water supplies must be analyzed, regulated, and, if necessary, improved through treatment and other management practices. Supplies and qualities of ground water reserves must be determined, and responsible planning provided for their continued use. Perhaps most importantly, effective and efficient strategies must be designed for aiding users to get the greatest possible benefit from the water they consume—in agriculture, residential uses, and industry, as well as for recreational purposes and the protection of natural environments.

Professionals have found modeling useful in virtually all aspects of these activities. Chapter 6, "Modeling and Water Resource Issues," presents 32 of the 33 specific issue areas in water resource management listed in table 1, and details the manner and extent of current model use for each. A broad and more general overview is provided below, to introduce the reader to the kinds of activities involved in model-aided water resource analysis and management. Italicized words or phrases represent issues specifically analyzed for this report, and addressed in chapter 6.

Perhaps the most striking example of man's interaction with the hydrologic cycle is *flooding.* In addition to the natural potential from spring rains, hurricanes, and the like, urbanization and other land-use activities can aggravate flooding problems. In 1975 alone, 107 lives were lost and $3.4 billion in property damage resulted from flooding. At the same time, $13 billion has been spent on flood management and control since 1936.[2]

To a degree, man has learned to manage floods. Dams have been constructed that can store floodwaters, releasing them gradually. Stream channels have been straightened and dredged to transport floodwaters more efficiently. More recently, nonstructural alternatives, including flood forecasting, restrictions on building in flood plains, and floodproofing, have received attention. Models have been widely used to assist in both structural and nonstructural flood management, including the design and operation of dams and other structural controls, the delineation of flood-prone lands, and advanced warnings of floods.

While some areas of the country are plagued with too much water, other regions may be troubled by a lack of it. Low rates of precipitation, both regionally and seasonally, can result in both *drought and low stream flows.* The Water Resources Council has identified 17 out of 106 water resource subregions that either have serious water deficiencies at present or are projected to have them by the year 2000.[3] Figure 1 illustrates the regions projected

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[2] U.S. Water Resources Council, *The Nation's Water Resources: 1975-2000,* (Washington, D.C.: U.S. Government Printing Office, 1978). (Hereafter: WRC, 1978).

[3] Ibid.

Photo credit: © Ted Spiegel, 1982

Spring flood on the "Red River of the North" inundates farmland on a 7-mile wide path, looking north from Grand Forks, N. Dak. Before man's arrival, nearby wetlands and lakes served as natural water sinks during spring thaws; many, however, have since been filled in for agricultural use. Man's tampering with the watershed causes increased flow rates, creating ice jams, water backup, and the overflow of manmade dikes. Models can be used to assess the probable extent of a flood plain under specified flow conditions; such information can be used to design regulations to govern the buildup of natural flood plain areas

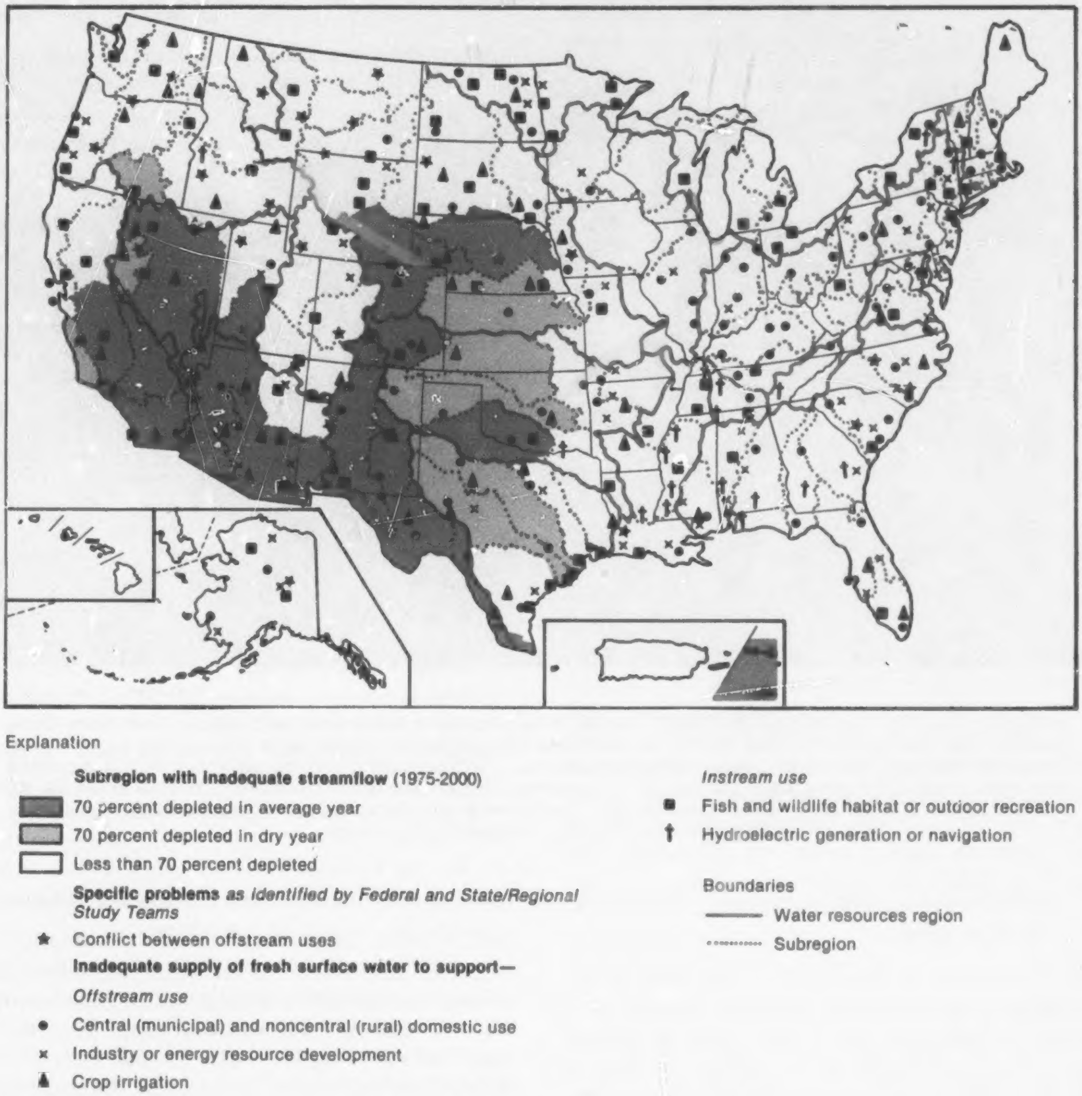
to experience surface water supply and related problems through 2000.

Models similar to those used for flood forecasting and control can estimate the frequency, timing, and extent of droughts or low flows. This information can assist reservoir managers in preparing for potential conditions of limited water or in instituting appropriate conservation measures prior to periods of water shortage.

Streamflow regulation is often associated with tradeoffs among competing objectives. For example, storing reservoir water for droughts may reduce the availability of water for downstream fish and wildlife habitats. Reservoirs must be operated to meet often-conflicting multiple objectives. Models can help evaluate the tradeoffs among these objectives, so that managers can determine an equitable strategy for operating reservoirs.

Conflicting objectives for water are not limited to reservoir operation; intense competition between instream and offstream uses also exists. *Instream flow needs* include adequate water for fish and wildlife habitat, recreation, navigation, and the generation of hydroelectricity. *Offstream uses* include *irrigated agriculture; domestic water supply;* and water for manufacturing, minerals, and energy production. When water is withdrawn from streams in the United States, about two-thirds is returned; the one-third not returned is termed "consumptive use." Among offstream uses, by far the greatest consumptive user of water is agriculture. In 1975, agriculture accounted for over 80 percent of the total U.S. water consumption.

Figure 1.—Inadequate Surface Water Supply and Related Problems


Explanation
Subregion with inadequate streamflow (1975-2000)
▩ 70 percent depleted in average year
▨ 70 percent depleted in dry year
☐ Less than 70 percent depleted
Specific problems as identified by Federal and State/Regional Study Teams
★ Conflict between offstream uses
Inadequate supply of fresh surface water to support—
Offstream use
● Central (municipal) and noncentral (rural) domestic use
× Industry or energy resource development
▲ Crop irrigation
Instream use
■ Fish and wildlife habitat or outdoor recreation
† Hydroelectric generation or navigation
Boundaries
—— Water resources region
······ Subregion

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000, Volume 1: Summary*, December 1978.

Total withdrawal of water for offstream use is expected to decline slightly by 2000 due to improvements in *water use efficiency and conservation*. Significant improvements in the efficiency of irrigation practices have been made through model-based analyses, resulting in major financial and energy-related savings, and alleviating demands on scarce ground and surface water reserves. However, while withdrawals are expected to decline by 2000, it is predicted that the annual consumption of water will increase by 27 percent over the same period.[4] This increase in consumptive use will aggravate the conflicts between instream and offstream water uses.

Decisionmakers at all levels of government are responsible for balancing these competing uses; a wide variety of models is available to assist the decisionmaker with this charge. Models can assist in allocating streamflow among conflicting users, and help forecast future water needs for formulating current policies, long-range planning, and management practices.

Despite the progress made over the last decade, the effects of municipal and industrial point source waste discharges on water quality are still widespread. About 90 and 65 percent of the Nation's river basins are affected by municipal and industrial discharges, respectively.[5] Figure 2 illustrates the regions of the country exposed to point-source surface water pollution problems. Models can estimate the ability of streams to assimilate pollutants from these various point sources so as to meet receiving water quality standards. Such *wasteload allocation* models are extensively relied on for planning purposes.

Thermal additions from electric power generation and manufacturing sources elevate stream temperatures, and can significantly affect aquatic life if the temperature rise or rate of change is great enough. Models are routinely employed to estimate the effects of thermal wastes from existing and planned facilities.

Dispersed nonpoint pollution sources are equally significant contributors of contaminants to the Nation's waterways, and are significantly more difficult to analyze and control than point sources. Figure 3 illustrates the areas of the country exposed to nonpoint pollution problems. An Environmental Protection Agency inventory estimates that about one-third of the oxygen-demanding loads, two-thirds of the phosphorous, and three-quarters of the nitrogen discharged to streams comes from *nonpoint agricultural sources*. Agricultural runoff, the most widespread nonpoint source problem, affects 70 percent of the country's major river basins.[6] Runoff and irrigation return flows contribute high concentrations of fertilizers, pesticides, herbicides, sediment, salts, and minerals. *Excessive salinity,* due to the leaching of salts from the soil by irrigation water, may affect receiving waters to the extent that they cannot be used for irrigation downstream. Models can be used to help farmers design "best management practices" to minimize nonpoint source agricultural pollutants.

Although *erosion,* and the resulting *sedimentation* in waterways, are natural processes, human activities—in particular, agriculture—have accelerated natural rates of soil loss. Sediments from erosion clog waterways and build up in the slower reaches of streams, lakes, and reservoirs. Sediments also carry such pollutants as phosphates and pesticides. Models are widely used to evaluate land-use management practices for minimizing soil erosion, as well as to assess the transport and deposition of sediments for river management.

Storm *runoff from urban areas*—containing oil and grease, lawn fertilizer, garbage, and soil from construction sites—affects half of the Nation's river basins. Models of urban runoff can be used to simulate the quantity and quality of pollutants from a particular area and to compare the effectiveness of alternative control strategies.

Airborne pollution is also a source of nonpoint contaminants. For example, the combustion of fossil fuels produces sulfur and nitrogen oxides, which have been linked to the phenomenon of "acid rain." While the ultimate effects of airborne pollutants are not certain, increased rainfall acidity has led to such effects as the loss of fish in sensitive lakes. Models that deal with acid rain and other airborne pollution to water are currently being developed.

Water pollution from both point and nonpoint sources can have harmful *effects on aquatic life.* Excessive concentrations of nutrients can cause explosive growth of aquatic plants. Organic wastes, such as sewage, can reduce oxygen levels in lakes and streams, adversely affecting fish. Models can be used to assist biologists in determining the effects of various pollutants on aquatic life.

Toxic pollution of drinking water is one of the most serious water quality problems facing the Nation today. The magnitude of the problem is large—

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[4] Ibid.

[5] *U.S. E.P.A. National Water Quality Inventory—1977 Report to Congress,* EPA-440/4-78-001.

[6] Ibid.

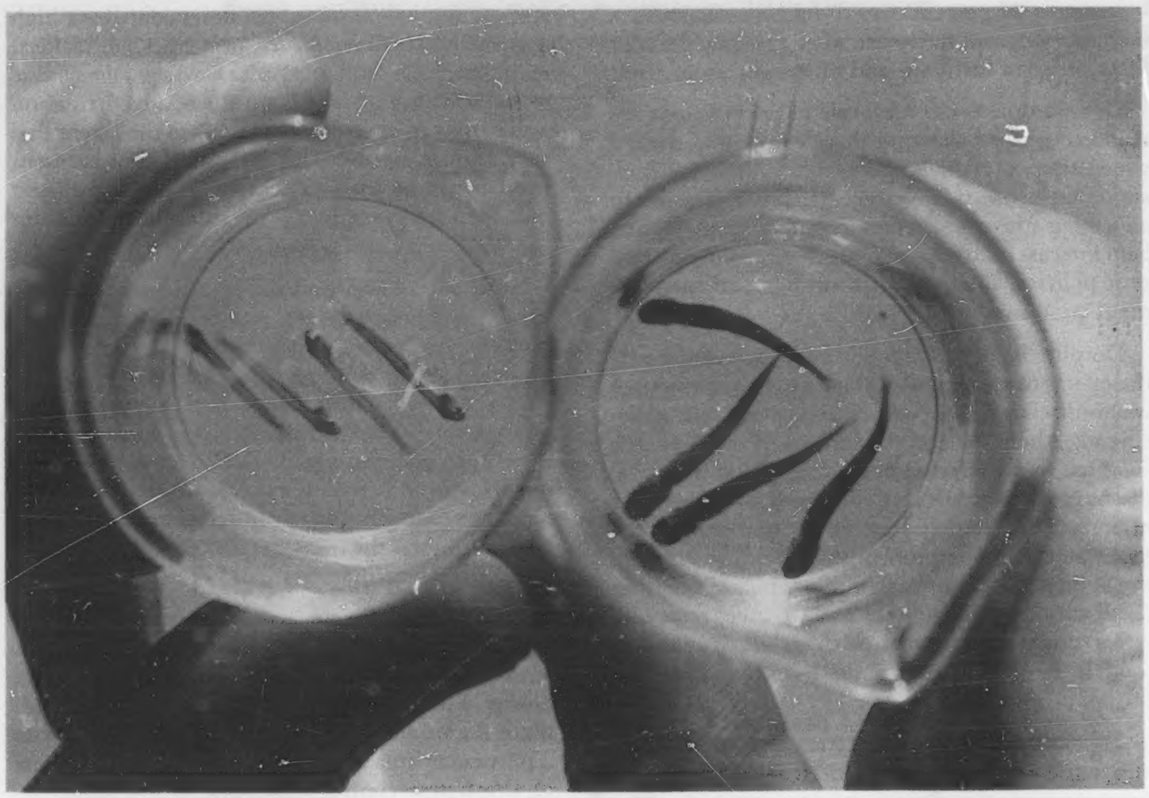

Photo credit: © Ted Spiegel, 1982

Fry at left have been raised with only 20 percent of the normal oxygen level of freshwater. The EPA laboratory in Duluth, Minn., performs experiments like these to determine what conditions are necessary to assure that offspring develop normally, like those on the right. Models that estimate oxygen levels in water bodies, when combined with laboratory data, can be used for estimating effects of actual conditions in rivers, lakes, and streams on aquatic life

30,000 chemicals identified as toxic to humans are presently produced commercially. Many toxicants are difficult to detect and remove using present technologies. Extensive potential exists for using models to trace the transport and fate of toxicants through the environment, and to test different management approaches for preventing toxicants from reaching water supplies.

Other agents of water-borne disease also pose threats to *drinking water quality,* including bacteria and viruses. Over 4,000 cases of water-related illnesses are reported each year, primarily from bacterial and viral sources.[7] While surface waters are extensively treated before distribution to users, ground water, which serves up to 40 percent of the population, is frequently consumed untreated from individual wells. Toxicology models, which relate concentrations of hazardous substances to human health, are used to aid in setting standards.

Stored underground in the Nation's ground water reserves is an amount of water equal to 35 years of surface water runoff. Nonetheless, ground water resources are exhaustible. Aquifers—water-bearing soil or rock—can be overexploited if ground water is removed faster than it can be recharged. Ground water "overdraft" can result in increased water pumping costs, declines in streamflow, land subsidence, and saltwater intrusion. Figure 4 illustrates the regions of the country experiencing significant ground water overdraft. Assessing *avail-*

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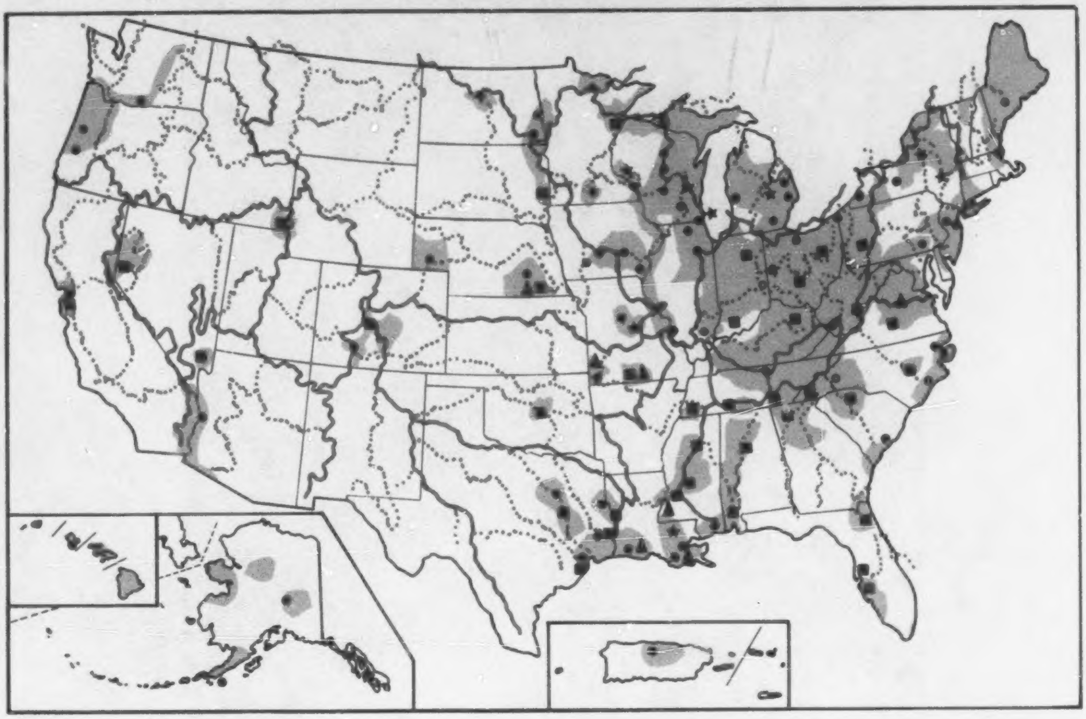
[7] WRC, 1978.

Photo credit: © Ted Spiegel, 1982

A soil scientist examines damage to cotton crop caused by excess salinity in the San Joaquin Valley, Calif.

Figure 2.—Surface Water Pollution Problems From Point Sources (municipal and industrial waste) (as identified by Federal and State/Regional study teams)



Explanation

Area problem

▨ Area in which significant surface water pollution from point sources is occurring

☐ Unshaded area may not be problem-free, but the problem was not considered major

Specific types of point source pollutants

- • Coliform bacteria from municipal waste or feedlot drainage
- ★ PCB (polychlorinated biphenyls), PBB (polybromated biphenyls, PVC (polyvinyl chloride), and related industrial chemicals
- ▲ Heavy metals (e.g., mercury, zinc, copper, cadmium, lead)
- ■ Nutrients from municipal and industrial discharges
- ◉ Heat from manufacturing and power generation

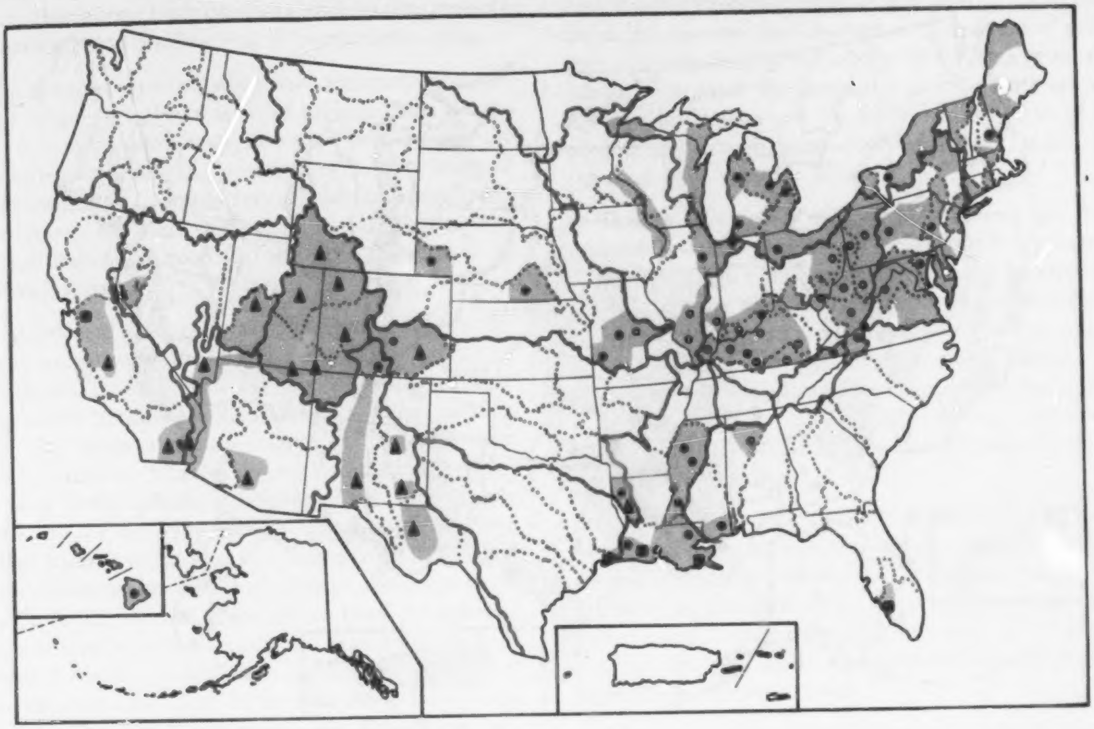
Boundaries

— Water resources region

----- Subregion

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000, Volume 1: Summary*, December 1978.

Figure 3.—Surface Water Pollution Problems From Nonpoint Sources



Explanation

Area problem

▨ Area in which significant surface water pollution from nonpoint sources is occurring

☐ Unshaded area may not be problem-free, but the problem was not considered major

Specific types of nonpoint source pollutants

● Herbicides, pesticides, and other agricultural chemicals

▲ Irrigation return flows with high concentration of dissolved solids

■ Seawater intrusion

○ Mine drainage

Boundaries

—— Water resources region

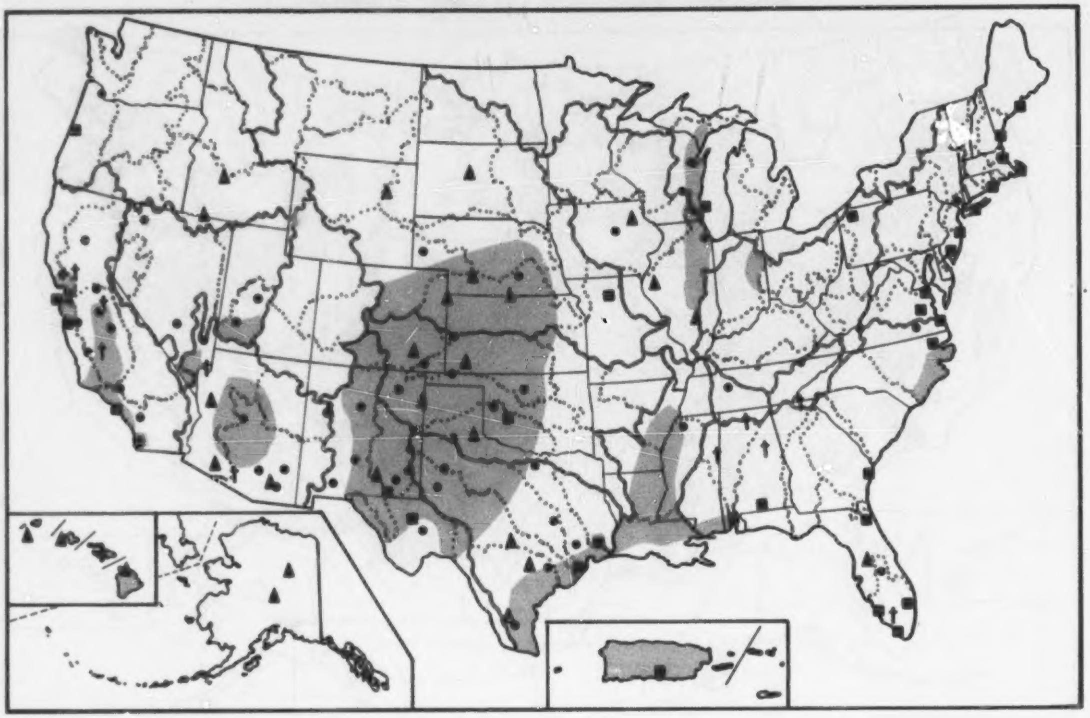
········ Subregion

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000, Volume 1: Summary*, December 1978.

able supplies and aquifer yields from individual aquifers is a pressing need; models are widely used tools for managing, regulating, and planning the use of ground water. Models can be used to design a well field for greatest efficiency, to assess the extent of usable supplies, and to predict water-level declines resulting from alternative development schemes.

In some areas, however, the excessive use of ground water has stopped too late. Major drops in ground water levels have caused the land to settle or subside, damaging buildings, roads, and railroads, and causing flooding in coastal areas. *Saltwater intrusion*—penetration of underlying saltwaters into the freshwater layer—has also been caused in

Figure 4.—Ground Water Overdraft and Related Problems



Explanation

Area problem

▨ Area in which significant groundwater overdraft is occurring

☐ Unshaded area may not be problem-free, but the problem was not considered major

Specific problems *(as identified by Federal and State/Regional*

- ● Declining groundwater levels
- ▲ Diminished springflow and streamflow
- † Formation of fissures and subsidence
- ■ Saline-water intrusion into freshwater aquifers

Boundaries

- —— Water resources region
- ---- Subregion

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources, 1975–2000, Volume 1: Summary*, December 1978.

coastal areas by excessive pumping. Similarly, ground water overdrafting may draw poor quality ground water near the land surface into deeper, high-quality ground water reservoirs. The likelihood of encountering these problems in a particular community or region can be assessed with models. Models can also help to evaluate management strategies to minimize the risk of such occurrences.

Many ground water users are now attempting to manage the *conjunctive use of ground and surface waters* to assure adequate water supplies. When available, surface waters are used to meet demands, while ground water is relied on primarily during dry periods. Ground water aquifers are often hydrologically connected to surface lakes and streams; models can be used to analyze their interaction and aid in their combined management, providing information about both quantity and quality aspects of ground and surface water interrelationships.

In the past, ground water was generally considered to be a reliable source of high-quality water. Yet pollutants from many sources enter the ground water system, though the extent and seriousness of contamination has only recently been recognized. Moreover, the ability of aquifers to rid themselves of pollutants is limited by the slow movement of ground water.

Accidental ground water pollution frequently went unnoticed due to the ubiquitous nature of contamination—from road salt, oil and gasoline, and other chemical spills and leaks. *Waste disposal* has also been a major source of ground water contamination. Wastes are sometimes injected into deep wells, which, if improperly designed, can contaminate drinking water. Toxic chemicals have found their way into ground water from municipal and industrial landfills and dumps. Seepage from septic tanks has for many years been recognized as a major source of bacterial contamination of ground water. In addition, *agricultural pollution of ground water* can occur from pesticides, fertilizers, and salts leached from the soil by irrigation waters. Once contamination occurs, the time and cost of reversing the process can far exceed the cost of preventing it. Models can be used to estimate the infiltration of these pollutants into ground water and the movement of contaminated water through an aquifer. They also have potential for aiding the design of waste-disposal landfills and injection wells to minimize the potential for polluting ground water.

Shortages of water, poor water quality, and flooding have obvious effects on society. Perhaps less obvious are the indirect economic and social effects that result from efforts to ensure or enhance water supplies and quality. The construction of a multipurpose reservoir, for instance, will bring an influx of construction workers from outside the local community. A part of the salaries these workers receive will be spent within the community, thus stimulating the local economy. An increased population, however, may also tax the local community's ability to provide adequate services such as education or police protection.

Part of the need to consider the *social impacts* of many water resource programs and projects stems from the uneven distribution of benefits and differing perceptions of the effects by various groups. Models can assist the decisionmaker by both organizing information on the social implications of a project and determining what social effects may occur and who may be affected.

Closely associated with social impacts are the *regional economic development implications* of water resource policies and projects. A new reservoir might stimulate increased recreational activities that subsequently attract new businesses to an area, or make a region more desirable for siting industries or utilities. Models have been developed that project changes in the level of local or regional economic activities resulting from water resource programs and projects.

The desirability of a project or policy may often be studied using a *benefit/cost analysis,* which attempts to assess relative economic efficiencies, weighing the monetary benefits of a project against economic costs. Models can be used both to assist in measuring the benefits and costs and to undertake the benefit/cost analysis itself.

The costs to industry of pollution control can also have economic implications that affect such factors as industry location and national inflation levels. Models are used to determine the impacts of these costs on economic indicators like the Consumer Price Index and the gross national product, as well as to determine the impact of these costs on specific industries.

Since the economic and social effects of water-related development extend beyond a project's immediate location, it is often important to analyze these effects on a regional basis. Water resource strategies can be developed through *unified river basin planning and management,* in which projected water use demands, water quality objectives, and numerous secondary considerations, including desired levels of economic development, are balanced and coordinated. Models are useful in many aspects of such planning.

Another analysis that is often necessary in the project-planning process is the consideration of uncertainty. *Risk/benefit analysis* weighs the probability of some outcome—a flood or drought—against the benefit that would potentially be derived, for instance, if a reservoir were built to mitigate the impacts of these floods or droughts. Models can help evaluate both the risks and benefits involved in projects to aid decisionmakers in determining acceptable levels of risk.

One influence on present use of water is price; raising the cost of water can reduce demand in some sectors, especially agriculture. This economic approach to conservation is particularly important because it can alleviate both the need for construction of expensive, large-capacity structural supply systems and the necessity for regulating water use. Models can determine the *effects of water pricing on use* by analyzing consumer response to price.

For regional and national analyses, *forecasting water use* requires an evaluation of population and economic growth, employment, industrial expansion, etc. to project future water needs. Models can estimate future levels of water use both by projecting past economic and demographic trends and by simulating the relationships between these factors and water use.

CASE STUDY OF MODEL USE: WATER RESOURCES IN LONG ISLAND, N.Y.

On Long Island, N.Y., water is a critical resource. Ground water is the sole source of drinking water for the island's 3 million residents and is endangered by contaminants from leakage of septic tanks, landfills, and other sources. Along Long Island's coast, rapid overdrafting of ground water has caused the intrusion of saltwater into freshwater aquifers. In addition, Long Island's rivers, bays, and estuaries, foundations of a fishing and tourist-based economy, are threatened by domestic and industrial wastes. In the past, contamination from these wastes has resulted in bans on fishing and the closing of public beaches.

In 1970, the Nassau-Suffolk Regional Planning Board found that the most obvious limit to future growth on Long Island was the availability of potable water. The board developed a Comprehensive Land Use Plan, which recommended seeking additional funds to conduct water quality studies on Long Island, and provided an impetus for more rational management of the island's water resources. Soon after, section 208 of the Federal Water Pollution Control Act of 1972 became the vehicle for undertaking these further studies and developing a regional strategy for treating and disposing of domestic and industrial waste. The

Photo credit: © Ted Spiegel, 1982

Refuse disposal on the Long Island coast has imperiled beaches and fishing in the past. Models of how pollutants disperse in Long Island's bays and estuaries can suggest areas for siting sanitary landfills to minimize the chance of significant damage

Nassau-Suffolk Regional Planning Commission was designated as the local agency responsible for carrying out this investigation.

In designing a waste management strategy, the commission relied heavily on models to provide a quantitative framework for making management decisions.[8] While water quality conditions were directly measured whenever possible, the geographic scope of the island and the expense of drilling test wells to analyze groundwater conditions precluded extensive direct measurement. The executive director of the Nassau-Suffolk section 208 study noted that a wide variety of models was necessary to provide information for evaluating alternative waste management strategies and plans:

> Long Island's $5.2 million 208 study could not have been completed without the application of management, physical, chemical, analogue and hydrogeological models. These models were necessary to help replicate a 1,200 square mile, geologically complex area.[9]

The nature of the management decisions facing Long Island also favored the use of models. To minimize the environmental impact of a wastewater treatment plant, for example, it is necessary to evaluate many alternative sites to determine its optimum location. The time and resources available for measurement limits the number of alternatives that can be evaluated. Models can help eliminate less desirable alternatives, focusing time and resources for detailed field testing on the most feasible sites.

Several options, for example, were available for managing the wastes of the Riverhead-Peconic area of Long Island (fig. 5). One or more regional, subregional, or local sewage treatment plants could be constructed to handle domestic wastes; alternatively, wastes could be diverted to the existing Riverhead plant. One factor in the decision was the relative impact of waste discharges from the various treatment alternatives. Several options were again available: dispose of the wastewater in Flander's Bay, discharge it into the Peconic River, or inject it or allow it to infiltrate into the aquifer. The commission also considered nonpoint sources of wastes and alternative means of controlling them—zoning, street cleaning, special agricultural practices, etc.

The commission had to use several models to evaluate the various alternatives. First, to determine the quantity of water and the amount of pollutants originating from nonpoint sources, the commission utilized a *water budget model*. For a given quantity of precipitation, this model projects the amount of water that will infiltrate the aquifer; return to the atmosphere via evaporation or plant transpiration; or reach rivers and streams overland. Changes in land-use practices—particularly the construction of impervious surfaces, like parking lots, and the removal of vegetation—alter the proportions of ground water infiltration, evapotranspiration, and runoff. The water budget model can respond to actual or hypothetical changes in land use by estimating changes in the proportional distribution of precipitation. In most cases, with increasing development, recharge to the aquifer decreases, while runoff normally increases.

An increase in overland runoff tends to increase the load of pollutants discharged—e.g., sediment from construction areas, grease from urban streets, and fertilizers from agricultural land. Runoff can thus contribute a major source of contaminants to water bodies such as the Peconic River and Flanders Bay. The water budget model can be extended to estimate the load of nutrients contained in urban runoff and the total input of these nutrients to the bay. Thus, as a planning tool, the water budget model can be used to: 1) estimate the effects of altering land-use practices to reduce excess runoff and ensure recharge of ground water; 2) estimate the effects of altering land-use practices to reduce sources of nonpoint source contaminants; and 3) determine the relative amounts of total bay and river system contamination contributed by nonpoint sources.

Other models are used to predict the impact of waste discharges from point sources on the Peconic River and Flanders Bay. These models simulate the currents and circulation patterns of these water bodies and project the transport and fate of pollutants once discharged. Different models must be used for the river and the bay because of differences

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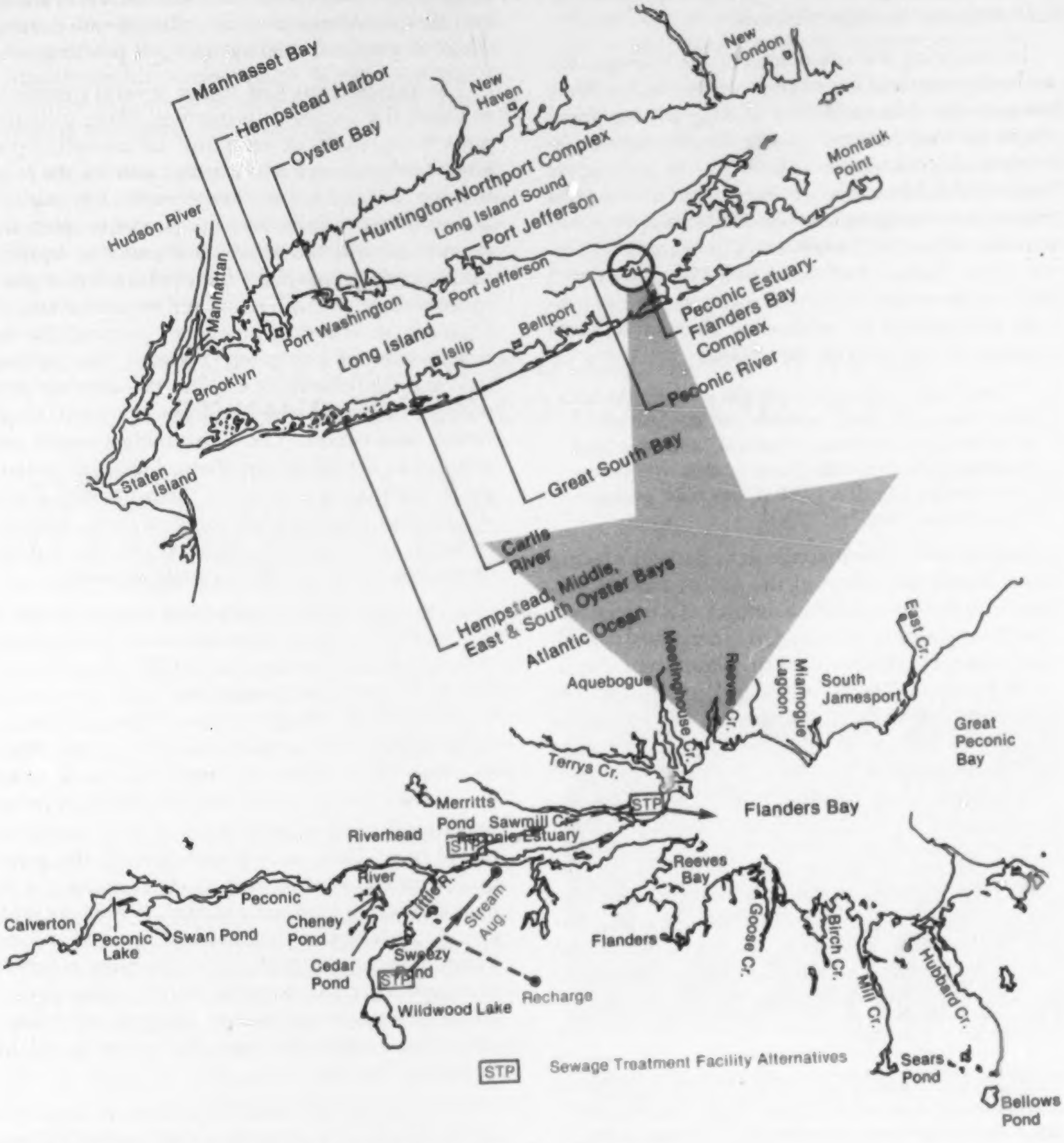
[8] *The Long Island Comprehensive Waste Treatment Management Plan*, Volume 1: Summary Plan; Volume 2: Summary Documentation (Hauppauge, N.Y.: Nassau-Suffolk Regional Planning Board, 1978).

[9] Lee H. Koppelman, personal communication to OTA staff, Nov. 24, 1981.

Figure 5.—Riverhead-Peconic Area, Long Island, N.Y.


Manhasset Bay
Hempstead Harbor
Oyster Bay
New Haven
New London
Huntington-Northport Complex
Long Island Sound
Port Jefferson
Port Jefferson
Montauk Point
Hudson River
Manhattan
Port Washington
Long Island
Islip
Bellport
Peconic Estuary-Flanders Bay Complex
Peconic River
Brooklyn
Staten Island
Great South Bay
Carlls River
Hempstead, Middle, East & South Oyster Bays
Atlantic Ocean
Aquebogue
Meetinghouse Cr.
Reeves Cr.
Miamogue Lagoon
South Jamesport
East Cr.
Great Peconic Bay
Terrys Cr.
STP
Flanders Bay
Merritts Pond
Sawmill Cr.
Peconic Estuary
Riverhead
STP
Reeves Bay
River
Peconic
Calverton
Peconic Lake
Swan Pond
Cheney Pond
Little R.
Stream Aug.
Flanders
Goose Cr.
Birch Cr.
Mill Cr.
Hubbard Cr.
Cedar Pond
Sweezy Pond
STP
Recharge
Wildwood Lake
STP
Sewage Treatment Facility Alternatives
Sears Pond
Bellows Pond

SOURCE: *The Long Island Comprehensive Waste Treatment Management Plan*, vol. 2, figs. 7-27, 7-28.

in their currents and circulation patterns. Not all areas of a bay or river disperse pollutants equally; e.g., some sections of Flander's Bay are isolated from its primary circulation patterns. Since nutrients stimulate algal growth, which can severely affect water quality, it is advantageous to rapidly disperse wastewater discharges to the bay. The river and estuary models can assist in determining an acceptable location for wastewater disposal.

The river and bay models assume that the growth of algae in these water bodies depends primarily on the concentration of nutrients from waste discharge. However, other factors like "grazing" of the algae by herbivorous zooplankton and recycling of nutrients from decomposing organic matter also influence algal populations. To account for these factors, the commission used an ecological model that simulates algal growth more accurately. The ecological model more fully explores the impacts of both point and nonpoint source discharges on the bay ecosystem.

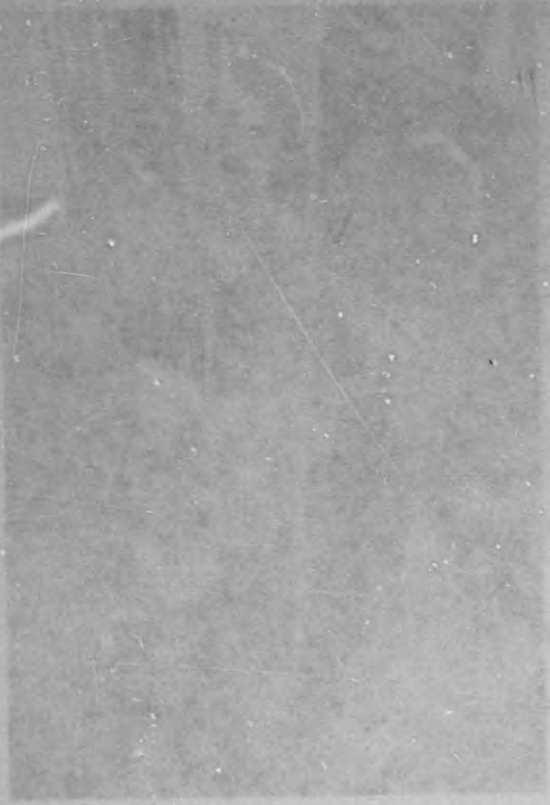
An alternative to discharging wastewater to the bay or river is to discharge treated effluents by either injecting them directly into the ground water or allowing them to slowly percolate into the aquifer. These approaches have the potential advantage of recharging declining ground water levels; however, they could also contaminate the ground water. Several different models were used to assess the impact of recharging ground water with wastewater in the Riverhead-Peconic area. One model type projects the effect of recharge on the height of the water table and the flow and distribution of recharge water in the aquifer.

A second model describes the way in which pollutants are transported with ground water flow. This type of model is used to estimate how a leaking septic tank, an injection well, or a recharge basin will affect ground water quality.

It is important to note that these models are not designed to make management decisions themselves. Many qualitative and quantitative considerations that affect management decisions are not within the scope of the models' analyses. For example, while a model may help to guide the selection of an adequate location for releasing treated sewage outflows in terms of water quality considerations, it does not consider many other factors, like a site's recreation or habitat potential, which are necessary aspects of the decisionmaking process. Models are virtually indispensable, however, for their ability to both describe and project, in a quantitative framework, the effects of alternative management decisions.

Photo credit: © Ted Spiegel, 1982

Construction crews prepare a wastewater injection well on Long Island. Wastewater will be pumped directly into the ground water table to prevent saltwater intrusion. Prior to construction, models were used to assess the injection well's potential to recharge (elevate) ground water levels, as well as to assess the possibility that wastewater could contaminate ground water supplies



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Chapter 3

General Issues in Model Development, Use, and Dissemination

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FIGURE

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6. Comparison of Measured and Computed Runoff for the Storm of Aug. 2, 1963—Oakdale Avenue Catchment—EPA Stormwater Management Model 57

Chapter 3

General Issues in Model Development, Use, and Dissemination

Models are increasingly used to analyze a wide variety of resource issues because they can provide information that is either unavailable from other sources, more accurate than that provided by other sources, or quicker and less costly than that provided by other sources. However, as with many new information technologies, institutions have encountered problems in integrating modeling and model-generated information with established operating procedures, professional responsibilities, and channels of communication.

When modeling efforts are supported by public funds, institutions that develop models have responsibilities for ensuring the availability and usability of such tools for other institutions. To effectively carry out these responsibilities, model-sponsoring organizations must devise strategies to inform potential users of the existence of relevant models, ensure that the model's purpose and workings are explained in writing so that decisionmakers can determine its applicability to a given problem, and disseminate the model to those who request it. Additional support services include developing programs to train and assist users to operate models and interpret results, maintaining and improving existing models, and designing models for ease of use by other institutions.

The process of developing and using models also requires extensive consultation between highly trained technical and scientific personnel on one hand and mid- and upper-level managers on the other. Yet decisionmakers are often unprepared to involve themselves in the modeling process, and may consequently be uncertain of how to use model results. Similarly, modelers may be equally unprepared to build models that provide the kinds of information decisionmakers need. For institutions to make effective use of models, links must be created among modelers, model users, and decisionmakers, and effective incentives be devised to make model development and use an interactive process among them. Further, institutions need to develop procedures for evaluating the models they use, overseeing model development, and assessing the legal implications and consequences of their model use.

This chapter reviews the major issues associated with the development, use, and dissemination of water resource models. Many of the significant problems associated with current model use for water resource analysis are encountered throughout the modeling profession; they tend to reflect the newness of the modeling field, and institutional unpreparedness for overseeing, supporting, and guiding model use.

The chapter is comprised of two major sections: Support Services for Disseminating and Using Existing Models Effectively; and Issues in the Development and Use of Models.

SUPPORT SERVICES FOR DISSEMINATING AND USING EXISTING MODELS EFFECTIVELY

Once a model is operational, any potential user normally needs a great deal of information from the developer if he or she is to become proficient in running the model and interpreting its results. A model may have been rigorously developed and thoroughly evaluated, yet in the absence of adequate user-oriented support services, it is likely to remain unused by anyone other than its developer. Within the modeling profession, such support services are called *technology transfer and assistance.* This section discusses those aspects of modeling that aid users in employing an existing model. Five support activities are treated in depth; the section concludes with an overview of additional model characteristics that are linked to technology transfer capabilities:

- documentation;
- informing users of available models;
- training;
- user assistance;
- maintenance and improvement of models; and
- additional model characteristics affecting ease of model use.

Documentation

Documentation is the process of setting out explicit written instructions on how to use a model and interpret its results. Although documentation is critical to the proper use and dissemination of models, it is rarely carried out adequately, and is considered by professionals to be one of the most neglected aspects of modeling. The lack of proper documentation prevents potential users from discovering existing models that suit their needs—causing costly duplication in model development—and increases the difficulty and cost of using previously developed models.

Documentation has two purposes. First, it provides a nontechnical description of the basic concepts employed in a model, and its limitations. Such a description must include sufficient information to allow a decisionmaker to determine whether a given model is suitable (and available) for a specific use. Second, it provides technical information on the basis of which a user/analyst can evaluate, duplicate, and operate the model. Three kinds of documents are generally used to document computer models:

1. a detailed description of the model's purpose and assumptions;
2. users' manuals, which give instruction on running the model—i.e., how to prepare input to get the desired output; and
3. programers' manuals, which explain the model's logic and internal functions, enabling the user to adjust and adapt the model to fit his particular needs.

Good documentation is difficult to prepare. Modelers and computer programers usually have a highly developed command of technical computer languages—it is in these languages that they actually work. Documentation requires translating the instructions written in these languages into clearly understandable English. The task is not only time-consuming—a medium-sized computer program may consist of 4,000 sets of instructions—but it is also one for which a technical specialist may have little skill or motivation. The developer of a model has no inherent need for documentation, other than as a reminder of what he may forget. Documentation is principally for successive users, and few incentives currently exist for the developer to take user needs into account in the process of model development.

Consequently, for most models, documentation either does not exist, or exists in inadequate form, lacking in detail, and failing to serve users' needs.[1] Model documentation is typically so brief or poorly written that the user is forced to resort to a trial-and-error approach to learn proper use of the model, or to seek personal assistance from those who developed the model.

Documentation is the primary mechanism for informed communication among those involved in modeling efforts—developers, users, analysts, and decisionmakers. Without it, the purpose, premises, and capabilities of the model remain obscure, and it becomes impossible to: 1) decide whether a model applies to a given problem, 2) operate the model independently of the developer, and 3) adequately interpret and use model results.[2] Further, competent documentation is important in facilitating model evaluation by third parties, and in encouraging continued maintenance and updating to keep models current.

Few institutions encourage proper documentation. Seldom are funds specifically provided for the documentation phase of model development. Even when funds are provided, if the funding organization lacks a unit that critically evaluates documentation in the context of using the model, developers may have little incentive to spend time and effort on the quality of their documentation work. In most modeling efforts, documentation is done "after the fact," as part of the cleanup operation at the end of the project, necessitating searches through old records at a point when both time and money are in short supply.

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[1] S. Gass, *Computer Model Documentation: A Review and An Approach,* NBS Special Publication 500-39, National Bureau of Standards, 1979.

[2] G. Fromm, W. L. Hamilton, and E. E. Hamilton, *Federally Supported Mathematical Models: Survey and Analysis,* GPO stock #038-000-00221-0 (Washington, D.C.: Government Printing Office, 1975), p. 44.

Moreover, modelers and programers have little professional incentive to produce high-quality documentation work. Documentation is a long and tedious process. Most developers see it as noncreative, in that it calls not for analytical or technical skills, but rather for communicative abilities that the modeler frequently lacks. At present, documentation is also seen as contributing little or nothing to the modeler's standing in his field.

If documentation is to be upgraded, it must become an integral part of model development. The most efficient mode of creating written documentation is to do so concurrently with the development of the model—this helps to ensure that the written instructions accurately reflect the actual computer program.

Informing Users of Available Models

Although numerous models are available to assist water resources managers, these models are difficult for users to identify, locate, and obtain. OTA found that many potential model users, and even modelers themselves, considered the need for effective communication about existing models more important than the need for developing new models. Frequently, the difficulty of identifying and locating a suitable model causes the decisionmaker to either forego model use for water management decisions, or leads to the development of a new model. Developing new models is extremely costly and time-consuming, while existing models that have been evaluated may need only minor adjustments and "fine tuning" to be applied to the user's problem.

Presently, most information on existing models is available only in technical journals. These technical publications are geared primarily to use by scientists and modelers. Few journals aim to communicate with decisionmakers and managers, and their distribution is often limited to a handful of subscribers. Most take over a year to publish a submitted manuscript, causing significant delays in communicating the availability of a model.

Three ways to make information on existing models available to potential users were suggested at the OTA workshops: 1) catalogs, 2) newsletters, and 3) model clearinghouses.

Catalogs

Various Government agencies and research organizations have published catalogs of available models. Such attempts to distribute model information have had mixed success. In the rapidly advancing field of modeling, many catalogs quickly become outdated, since new models are regularly introduced and old models must continually be updated to remain current. Consequently, the maintenance and updating of a usable catalog must be performed on a continuing basis by a staff with relatively high levels of expertise.

A number of Federal organizations have included model-related information in catalogs dealing with water resources—most importantly, the *Selected Water Resources Abstracts* and the *Water Resources Research in Progress File Catalog* of the Water Resources Scientific Information Center, and various publications of the National Technical Information Service. However, these services are not designed to rapidly access modeling information, and are too far removed from developers to be extensively used or adequately maintained.

In addition, the Federal Software Exchange Center (FSEC) publishes catalogs of computer programs that Federal agencies consider to be usable by other Federal, State, and local government agencies. However, the catalogs are not intended to provide comprehensive coverage of even federally developed models, and provide relatively scanty information regarding the models that have been included. Moreover, FSEC regulations prohibit disclosure of the identity of the developing agency without its prior consent, frequently precluding further inquiries by and assistance to potential users.

An extensive discussion of the functions of these organizations that relate to modeling is provided in chapter 4 of this report.

Newsletters

Newsletters are a useful vehicle for disseminating information about available models. An organization can publish newsletters relatively inexpensively as a service to current and potential users of its models. Newsletter services for the Environmental Protection Agency's (EPA) Stormwater Management Model (SWMM) Users's Group and the EPA Center for Water Quality Modeling are described in chapter 4 of this report.

Model Clearinghouses

Clearinghouses offer a comprehensive approach for disseminating information about models available from a broad range of participating agencies and organizations. Model clearinghouses serve as a central resource for obtaining information about available models, and help to address such modeling problems as duplication of model development efforts, and improper selection of models.

A clearinghouse's primary function is to collect models and model-related information, and disseminate these models and information to the user community. The majority of persons contacted for this study indicated a strong need for a model clearinghouse. One established clearinghouse for ground water models at the Holcomb Research Institute is discussed in chapter 4 of this report.

Of those surveyed by OTA, most who favored the model clearinghouse concept felt that the clearinghouse's primary or central role should be to inventory existing models. This inventory might consist of a central catalog of models by subject area, a list of available models, a list of agencies that use models, and a notation of a contact person or agency for further information about each model. For Federal agencies, an inventory would help avoid duplication of existing models and could improve interagency coordination of modeling efforts. For State agencies, an inventory would serve as a source of information on available state-of-the-art modeling tools.

To meet model users' needs, the clearinghouse could also establish a catalog of model characteristics to help users compare the advantages and disadvantages of different models. Users seeking information on a particular model, or on models for a specific problem, would submit information on the nature of the pertinent water resource problem and on any other requirements that influence the choice of a model—such as cost, level of complexity, assumptions of the model, etc. In turn, trained clearinghouse staff could quickly locate models that generally fulfill these requirements.

Clearinghouses can provide assistance in other areas as well. State survey respondents indicated a need for information on sources of technical assistance, training, and data, as well as information on existing models. Some respondents suggested that clearinghouses serve as technical assistance and training centers. Clearinghouses could also have evaluative functions—developing standards for assessing the materials submitted, and providing technical help in evaluating the utility of available choices.

It is unlikely that a clearinghouse could initially be self-financing. Seed money would invariably be needed to get it started, and outside funding might be needed throughout its existence. Clearinghouses could be partially funded by private business or Federal agencies, and earn the remaining necessary operating funds by charging for their services. Another option is for the clearinghouse to conduct and charge tuition for training courses, which would publicize the organization as well as generate income.

Training

User training is among the most effective means for improving the use of water resource models. Both model developers and model users who were contacted during the OTA study consider training an important aspect of model support. At the present time, neither governmental water resource agencies nor the private sector are providing the necessary training for applying models to the decisionmaking process. In response to an OTA survey, State-level water resource professionals ranked federally sponsored training a priority second only to data needs, and indicated a need for training assistance in all phases of modeling activities.

Several mechanisms can be employed for training model users and decisionmakers. Individuals surveyed for this study generally agreed that one-

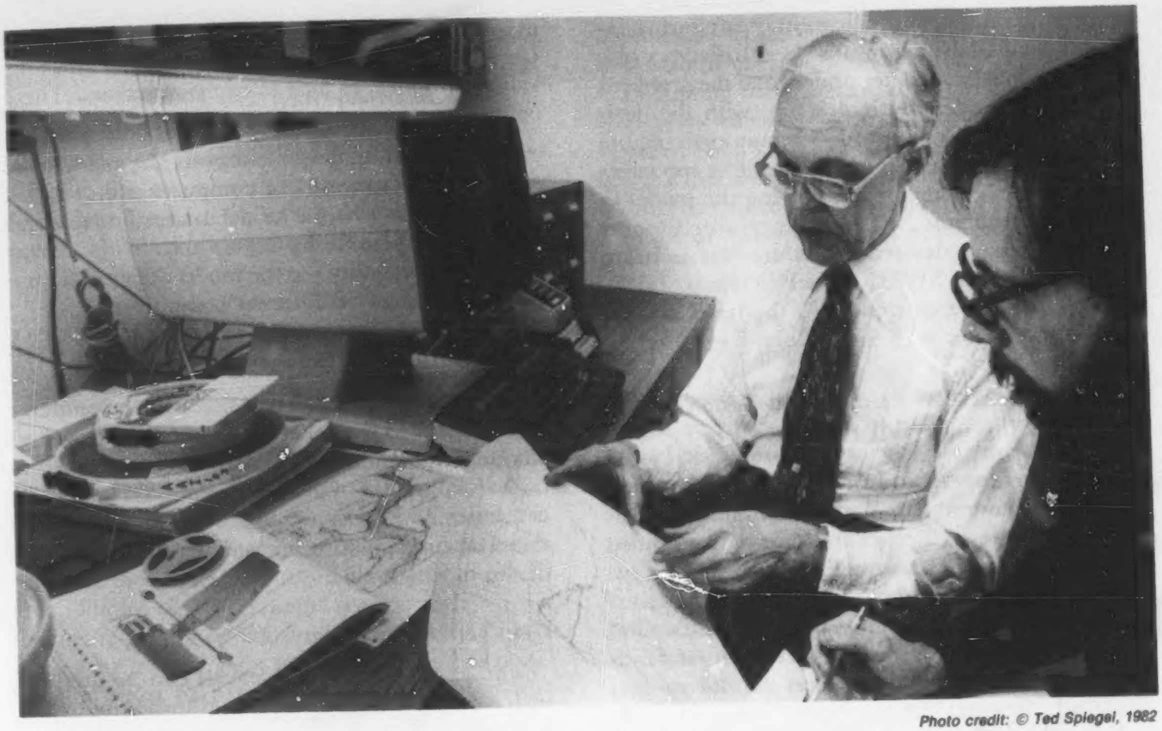

Photo credit: © Ted Spiegel, 1982

A senior hydroligist at USGS headquarters in Reston, Va., demonstrates steps in modeling river currents. A tape from the underwater monitoring equipment pictured in left foreground provides data as input to the model, which is run on the computer terminal above. A portion of the model converts numerical information into charts and maps of current patterns in the river itself.

to-one interaction between developer and user is the most successful training approach; however, it was also identified as the most expensive training method. Hands-on workshops, which allow users to run models on computers under supervision, were identified as the next best method. Traditional seminar approaches were the third choice for user training.

A number of Federal agencies conduct user training programs. The U.S. Geological Survey conducts numerous courses in many aspects of modeling, while the Army Corps of Engineers' Hydrologic Engineering Center (HEC) provides extensive training courses in the use of its major models. The Instream Flow Group (IFG) at the Department of the Interior specializes in training both managers and technicians in instream flow analysis, problem solving, and related model use. Federal training efforts are described in detail in chapter 4 of this report. Some agencies are using videotapes of training sessions as less expensive teaching tools. Other innovative techniques may be applicable to training model users, including programed teaching aids and self-instruction methods.

User Assistance

Documentation, training, and other user aids can go a long way in preparing the decisionmaker for using water resource models. However, direct assistance by experienced modelers and computer programers will often be needed. Sometimes the problem can be solved simply by a phone call; at other times, direct contact with a modeler or programer who is familiar with the model may be needed.

User assistance may range from merely providing information on the status of a new model, to advising on model application or preparing input data and analyzing results. User assistance also helps the modeler to better understand the problems of applying models by interacting with the decisionmaker-user. Complex models may even require "tutored application" in which modeling specialists and users work together in applying the model to the user's problem. Federal agency user support groups that have devised procedures for assisting users include the SWMM User's Group, HEC, and IFG. Their experiences in this area are described in chapter 4 of this report.

Maintenance and Improvement of Models

The development and improvement of models seldom stops at evaluation and fine-tuning for real-world applications. Models are constantly modified and improved based on users' experience, new information, or new methodologies and techniques. Each change in a model must be documented, and the users notified of the modification and adjustments in operating procedures that it requires.

It is important that the institutions that sponsor and support model development make provisions for updating and maintaining models after they become operational. Unfortunately, history has shown that few institutions, whether Government agencies or academic institutions, provide for the contingencies of model updating and maintenance. Clearinghouses or central repositories can play an important role in ensuring that models are updated and improved. OTA workshop participants suggested assigning "lead agency" responsibility to a Federal Government entity for systematically tracking Government-wide model development and upkeep.

Modeling support groups such as HEC are effective means for assessing model deficiencies, maintaining and improving a model, and notifying users of subsequent changes in a model.

Additional Model Characteristics Affecting Ease of Model Use

In addition to the technical assessment of a model's capabilities and the qualitative evaluation of its credibility through operational testing (described in the following section, *Issues in the Development and Use of Models*), there are other factors that affect the value of models as aids to decisionmakers. These incude:

1. computational efficiency—is the model cost effective in terms of computer use;
2. ease of use—is the model understandable and easily operable by users; and
3. transportability—is the model designed for use on a range of different computers?

Computational Efficiency

Computational efficiency pertains to computer costs associated with operating a model. It is generally achieved by carefully designing the model to make the best use of the capabilities of a particular computer and by applying state-of-the-art procedures for manipulating and solving equations within the model itself.

Ease of Use

The ease with which a model can be used depends on the design of its input and output characteristics. The input characteristics of a good "user-oriented" model, i.e., a model that is designed for use by persons other than the modeler, ensures that information and data needed for running the model can be introduced into the model with the least effort and with minimum chances for errors. Such a model checks the data for completeness and reasonableness, and transforms it into usable form for processing. The output of a good user-oriented model can be adjusted to provide the level of detail and organization of information that best suits the user. If a computer run cannot be completed due to errors or incompatibility of data, an effective model will provide an analysis of the problem encountered (diagnostic information), and will warn when computer-generated information exceeds predetermined bounds.

Transportability

Model transportability is the ease with which models can be transferred from one computer system to another. Characteristics of computer systems vary substantially among manufacturers. A model designed to take full advantage of the various features of a particular computer system, e.g., for storing information or solving equations, may need major revisions for use on another computer system. Costs associated with restructuring and retesting models can be substantial. If a model is intended for use on a number of different computer systems, the modeler must avoid using system-dependent features of any particular computer system. However, designing a transportable model often results in sacrifices of computational efficiency and ease of use.

Designing for transportability requires knowledge of the characteristics of a variety of computer systems. Such knowledge is difficult to acquire and is not widespread among model developers, since it must be gained through operating experience on a range of computer systems.

ISSUES IN THE DEVELOPMENT AND USE OF MODELS

The model development process begins when a decisionmaker, scientist, or manager identifies an information need that can best be met through some form of mathematical analysis. A team of professionals subsequently analyzes the issue and gathers data on it, develops the mathematical equations that comprise the model, fine-tunes the model to specific conditions, evaluates model results, and presents the model-generated information to the individual requesting it. Oversight from the supporting organization must be provided to assure that model development proceeds effectively, and that model results are appropriately used. This section assesses four major aspects of the process of developing and using mathematical models:

- interaction between modelers and decisionmakers;
- evaluating models for use by water resource managers;
- mechanisms for assuring adequate oversight of model development; and
- legal aspects of model use in administrative processes.

Interaction Between Modelers and Decisionmakers

The goal of the modeling process is normally to provide results that are usable in decisionmaking processes—including day-to-day operations and management, medium- and long-range planning, regulatory purposes, and policymaking. To effectively aid decisionmaking, models must provide information that is relevant to the decision alternatives at hand. In addition, model results must be considered reliable by those responsible for making decisions.

Because modeling is a relatively new field, few decisionmakers have had an opportunity to use models as part of their formal education, or to participate in model development processes. While this trend is changing as a new generation of water resource managers assumes positions of responsibility, lack of familiarity with models and modeling concepts remains a key impediment to increased reliance on model-based information. Individuals contacted or surveyed by OTA repeatedly stated that models are not used in many water resource areas because "they are not trusted" by those responsible for management and decisionmaking. Conversely, models tend to enjoy high levels of credibility among users and decisionmakers who are familiar with modeling techniques and with the results of specific models.

Managers who are inexperienced in the use of these techniques tend to base their judgments about the value of models on the experience of others. Dr. William Johnson of HEC observed that "the criterion of trustworthiness is determined by an acceptable record of use (preferably by those other than the model developer)." Results of OTA surveys and workshops on modeling[*] suggest that the use of models in water resources management can be broadened by a concerted effort to familiarize resource managers and decisionmakers with the development and operation of mathematical models.

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[*] OTA sponsored a series of workshops for modelers from the Federal Government and the private sector in October and November of 1979, results of which are summarized in ch. 4 and app. A. A written survey of water resources professionals working at the State government level was conducted in May of 1980, results of which are summarized in ch. 5 and app. E.

When a decisionmaker initiates a model development effort, the value of the information he ultimately receives depends directly on his ability to specify what he needs to know. Yet many professionals routinely state their information objectives in qualitative terms, and their conception of the problem to be solved may not lend itself to quantification. Decisionmakers may also look to the model to explain the issue, when in fact a clear specification of the issue is a prerequisite to developing models of it.

A modeler who is confronted with an imprecise request for information will normally attempt to provide the kind of results that he or she considers critical to the decision—often without success. Modelers usually have a technical or scientific background that is significantly different from that of the decisionmaker, although there are some exceptions. Without inputs from decisionmakers, modelers may tend to concentrate on "technically correct" solutions without regard to political considerations that may affect the outcome of a decision.

HUDSON RIVER VALLEY COMMISSION OF NEW YORK

Photo credits: © Ted Spiegel, 1982

Evidence that PCB levels in the Hudson River had the potential to interfere with commercial shad fishing led the New York State Hudson River Valley Commission to develop models to analyze the problem

Modelers may also have professional motivations that lead them to concentrate on developing modeling techniques and mathematical sophistications for the primary purpose of advancing the state of the modeling art. Rewards are frequently given on the basis of professional contribution to the field of modeling rather than for developing models that have utility for the decisionmakers. A 1975 survey of model development project directors conducted by Fromm, Hamilton, and Hamilton,[3] found that the two most frequently identified benefits of modeling were: 1) "educated the model builders" (78 percent); and 2) "pointed a way for further research" (76 percent). "Helped in making policy choices" ranked only fifth (58 percent). The modeler's preoccupation with advancing the state of the art of modeling, while highly useful for anticipating future needs and identifying critical emerging issues, often leads in the short run to overly complicated models that require more information and data for their use than is practically available to the user/decisionmaker.

Finally, unless the modeler thoroughly instructs the decisionmaker on how to interpret model results, the information provided may inadvertently be misleading. By constructing the model, a modeler normally gains an appreciation of its capabilities and limitations—in particular the range of error associated with various model results. If the decisionmaker is merely presented with a set of figures and projections, he or she may tend to overrely on the model's accuracy or misinterpret the meaning of the information produced. Such overreliance may result in a misdirected decision, and cause the decisionmaker to avoid the use of models in the future.

The most effective way to avoid these pitfalls in model development and use is to ensure that modelers and decisionmakers interact and communicate with each other throughout the model development process. The institutional setting should encourage multidisciplinary approaches to problem solving, involving scientists, modelers, model users, and manager-decisionmakers. The success of the modeling effort will often depend on stimulating and maintaining communications among these groups.

The modeler-decisionmaker team needs to ensure that four questions are continually addressed during model development or use:

- Are we developing or using the model to answer the proper questions?
- Is the model capable of producing sufficiently accurate answers?
- Will the model be an improvement over existing techniques?
- Will the improvement in results justify model costs?

Neither model developers nor decisionmakers can answer these questions in isolation from each other. But bringing the expertise of each group to bear jointly on model development and use is in itself a complex undertaking. Creating appropriate incentive structures in institutions where modeling activities take place can have a major influence on how well the interested parties work together to produce appropriately designed models. The professional climate established by top policymakers plays an important role in encouraging the use of models, training decisionmakers to use models effectively, and stimulating the development of usable modeling tools.

Evaluating Models for Use by Water Resource Managers

Once developed, models must be evaluated to ensure that the information they generate adequately covers the range of conditions that the decision objectives demand. This requires not only an assessment of the technical capabilities and limitations of the model, but also qualitative judgments concerning the nature and extent of the information needed for the decision at hand.

The evaluation process aims to answer three questions concerning the model:

- How well does the model's structure correspond to the structure of events in the real world? Since models are simplified mathematical representations of real, complex relationships, we need to know how adequately such simplifications reflect the essentials of these real-world relationships. Are the model's assumptions about real-world behavior reasonable? Does the model take account of the factors that actually characterize and control the real-world phenomenon? Is the model sensitive to changes in those factors that could affect the real-world response?

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[3] Fromm, Hamilton, and Hamilton, op. cit., p. 66.

- How accurately does the model predict events in the real world? What is the degree of possible error gaged by some measure of performance?
- Does the model provide the degree of accuracy and flexibility required by the user? Is information provided at an appropriate level of detail?

The first question is conceptually the most difficult, and requires both technical and qualitative analysis of any given model. The second is quantifiable and can be addressed by a procedure called "validation." The third addresses the relevance of the information provided, and involves subjective analysis of the nature of the problem being studied. Modelers and decisionmakers must understand the outcomes of all three kinds of questions if they are to evaluate the models they use and the information that models provide them. The following discussion outlines the major techniques used to provide these answers.

Photo credit: © Ted Spiegel, 1982

Researchers take ice core samples to measure PCB deposits at Thompson Island Dam, Ft. Edwards, N.Y. Often, data-gathering must be closely coordinated with modeling activities if models are to provide information relevant to the problem at hand. Models can also be used to help pinpoint those aspects of the problem for which additional data collection is required

Technical Assessment of Models

Three technical procedures collectively determine the accuracy of a mathematical model: 1) verification—assuring that the computer program actually performs as designed; 2) calibration—developing values for the constants and coefficients in the computer program from field data, in order to accurately predict real-world events; and 3) validation—assessing the model's accuracy in predicting real-world events.

Verification.—A model is said to be verified when it is determined that the designer's conception of the model is accurately embodied in the program written and run on the computer. Such a procedure is applicable to any model, and involves technical checks to ensure that:

- the written program accurately describes the model's design;
- the program is accurately mechanized on the computer; and
- the mechanized program runs as expected.

Verification of a computer model may require considerable effort to "debug" (adjust the program so that it runs properly), particularly if the model is large and complex. Although the process of verification is straightforward, and to a large extent mechanical, the expense and time delays to debug a program can be significant.

Calibration.—Models must be "fitted" or "fine-tuned" to the specific characteristics of the real-world system being studied. Each model contains a set of "parameters," i.e., values of coefficients, that establish the relationship between the model's predictions and the information supplied to the computer for analysis. A model is considered to be calibrated when model results match experimental observations taken from the particular system under investigation. Calibration is, thus, the procedure used to determine a specific mathematical value for the parameters of a model.

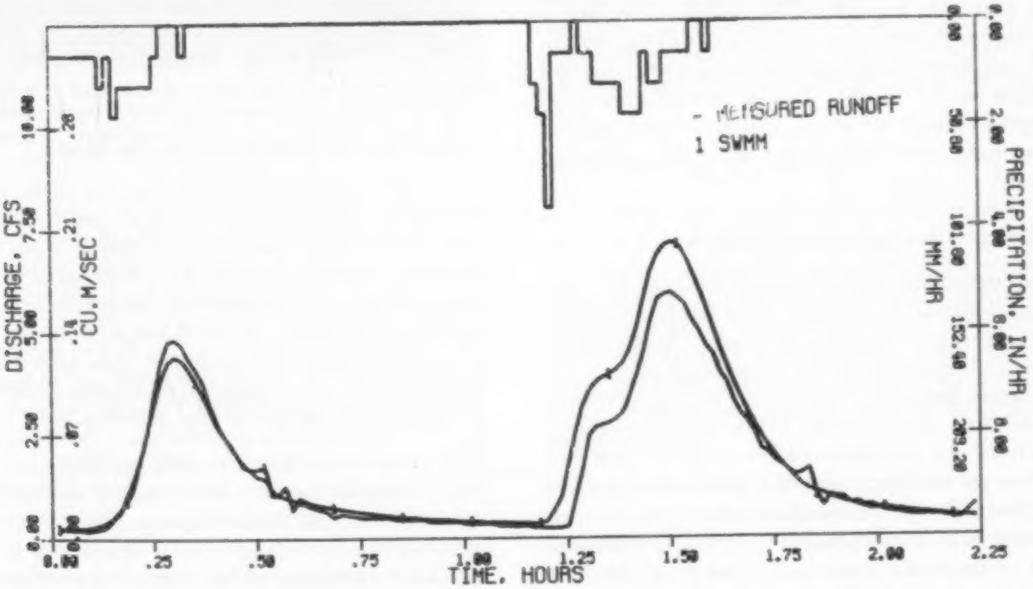
Calibration depends on a reliable set of data collected under conditions as similar as practical to those prevailing at the time of the decision. Often, however, data are not available, and the modeler must depend on assumed values or average values observed previously for estimates of the parameters. The use of assumed or hypothetical values often reduces the reliability of the model.

Validation.—Validation is the process of determining how accurately the model can predict real-world events under conditions *different* from those on which the model is developed and calibrated. To validate a model, a different set of field data is used as input to the model and the output is compared to actual observations of the new field conditions. Where possible, validation uses a completely new set of data, gathered at a different time or place than those data used to develop and calibrate the model. However, in instances of limited data, a single data set may be split, and the two halves be used for calibration and validation respectively.

The simplest validation measure is a graphic comparison of observed data and computed values. It allows the analyst to make qualitative judgments about the adequacy of the model and its suitability for additional use, and provides a clearly visible, easily understood assessment of model results. An example of simple graphic comparison is present in figure 6. More complex models may require statistical indicators of accuracy to supplement or supplant graphic presentation. Simple statistical measures comparing observed and computed values include correlation coefficients, computation of relative error, and comparison of means.

Validation depends on a reliable standard for comparison. The lack of comparative data often

Figure 6.—Comparison of Measured and Computed Runoff for the Storm of Aug. 2, 1963—Oakdale Avenue Catchment—EPA Stormwater Management Model



The graph above compares measured runoff to SWMM estimates of runoff for a single storm event at an individual stormwater catchment. Amounts of precipitation falling during the course of the storm are shown at the top, and are calculated by the scale at the right; actual and estimated discharge to the catchment is shown by the lower lines, and is measured by the scale at the left.

SOURCE: EPA Stormwater Management Model.

precludes adequate validation. If a model describes a unique system or event, then comparisons with data from other systems (or times) may be impossible. Some models, e.g., models of physical processes which are governed by law of physics and engineering, are often adaptable for a wide range of applications. Such models can be validated from time-series observations at a single location—comparing results with prior historical data—or in combination with similar data from other locations.

Social and economic behavioral models, however, are difficult to validate in the strict sense. Human behavior cannot be analyzed in the same sense as interactions that take place in the physical sciences. Human interactions may be extremely complex, and involve many factors not readily subject to quantification. At best, social scientists can estimate statistical variations in human behaviors under a set of assumed conditions—yet there is no way to gage the likelihood that the assumed conditions will come to pass. This difficulty is compounded by the necessity to forecast changes in a number of highly uncertain economic and social variables, e.g., inflation, commodity prices, and demographic and employment patterns. Moreover, the complex interactions of the economic and social systems are dynamic, i.e., the nature of the system itself continues to change, thus requiring constant changes in the model. Under circumstances of changing system structure, it is nearly impossible to use long-term time-series data for validating models.

Qualitative Assessment of Models

Socioeconomic and integrated models are used by decisionmakers to predict the likely economic and social effects of policy decisions. As explained above, such models cannot be validated in the technical sense because there are no statistical means for assessing the accuracy of the model's predictions until the predictions have come to pass—or failed to do so. Moreover, the presence of factors that have influenced the outcome but have not been included in the model may preclude any statistical check on the model's accuracy. One must therefore rely on qualitative indicators of the model's credibility and reasonableness to assess its usefulness and reliability. Properly understood, such procedures permit policymakers to determine whether a model's predictions are sufficiently reliable to serve as an input to decision processes.

Three techniques can be used to assess complex predictive models in a qualitative or semiquantitative manner: 1) parts of a complex model can sometimes be validated independently of the remainder of the model, using historical data to test the accuracy of the projections; 2) professional consensus can be obtained among experts who review the reasonableness of the model's parameters and structure; and 3) users can perform sensitivity analyses, i.e., comparing the changes in model output that result when the model is run successively with small changes in model assumptions. Sensitivity analysis places less emphasis on the absolute accuracy of projections, and more on the differences that result from incremental changes in policy, for example.

The decisionmaker must be a major participant in the qualitative assessment of a model. In the absence of statistical and objective measures of performance, one must rely on the intuition and experience of the decisionmaker in judging the quality of the information the model supplies and in weighing that against the informational needs for decisionmaking. Similarly, the user/decisionmaker must be the final arbiter in evaluating the sensitivity of the model to changing inputs and conditions.

Assessing the Relevance of the Model

A major reason for expending the time, effort, and funds necessary for using a model is to provide information that is not available from other sources. A model's utility to the decision process depends both on its ability to analyze information and on the relevance of the information to the decisions to be made. Thus, in the final analysis, the decisionmaker must gage the usefulness of the model against the profile of the decision itself.

In some instances, a model's primary use may be to identify further information that may be needed to approach the decision; thus the evaluation of the model proceeds as an integral part of the issue analysis. The term *forum analysis* is sometimes used to indicate a procedure in which a number of models are analyzed to determine their relevance to a given issue. The forum analysis begins as a comparative exercise, in which different

Photo credit: © Ted Spiegel, 1982

Decisionmakers must understand the assumptions underlying model-generated information to use it in deciding policy questions

models are run with the same data set in order to determine the fundamental differences in their procedures and results. The information generated is then used as a focal point for examining the issue itself, as participants attempt to specify the factors that influence the situation in the real world, and to improve the model's capacities to reflect those factors. The "forum" for carrying out this assessment simultaneously involves modelers, model analysts, and policymakers. Forum analysis can be a powerful tool to advance the state of the art of modeling for a specific problem area, and can also contribute to a better understanding of the problem by providing an analytical framework for considering the issues.

A recent World Meteorological Organization forum analysis project compared 10 hydrological models that provide short-term forecasts of streamflow.[4] The project used data sets from six rivers with different physical and climatological characteristics to determine the models' relative advantages and disadvantages for assessing streamflows in a variety of river types, and under differing institutional constraints and accuracy requirements. The exercise allowed participants in a technical conference to compare the performance of the tested models, and to develop guidelines for model selection based on such criteria as the purpose of the forecast, the prevailing climate within the river basin, and the quality and type of data and computers available.

Mechanisms for Assuring Adequate Oversight of Model Development

Although there is broad agreement among the modeling commmunity that additional measures are needed to standardize and improve the quality of models, there is significant disagreement among modelers as to how this should be achieved. Among the means of ensuring quality control of models are: guidelines, standards, contractual agreements, and peer review. Each of these could potentially limit the individual modeler's flexibility and freedom to approach problems, hence any proposal to create standards and impose uniformity is a contentious issue.

Guidelines and Standards

Proponents of establishing Government-wide guidelines for model evaluation consider guidelines an effective means of standardizing and ensuring compatibility among model development efforts, as well as a way to screen bad models while enhancing the acceptance of good ones. Such guidelines could promote uniformity in evaluation criteria, and contribute to achieving compatibility among model results.

Opponents point out, however, that the wide variety of user needs may preclude the use of uniform guidelines. Since a model needs primarily to match the informational needs of an individual user, the user is in the best position to determine appropriate standards. Guidelines written to deal with a range of models would likely be either too vague to be potentially useful, or limited in applicability to a few specific models. In either case, guidelines could inhibit innovative modeling efforts which depart from accepted practice. This could inhibit advances in the state of the art in modeling research.

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[4] "Intercomparison of Conceptual Models Used in Operational Hydrological Forecasting," World Meteorological Organization, WMO No. 429, Geneva, Switzerland, 1975.

A further difficulty arises in the use of guidelines within an organizational framework. Procedures intended as general suggestions to *guide* model development and use may tend in practice to be used as *standards* governing modeling activities. A manager's natural desire to minimize risk and preclude responsibility for failure could place pressure on users and developers alike to follow accepted, conventional procedures. In the rapidly advancing field of modeling, such a bias could conflict strongly with the objective of incorporating the best available knowledge into current modeling activities.

A General Accounting Office (GAO) report[5] supports the guideline concept, while acknowledging that variations in model development efforts require that guidelines be highly flexible. GAO's survey of model developers in the Northwestern United States revealed skepticism about guidelines—both in general, and in reference to specific GAO proposals:

> A primary concern was the fear that the guidance factors could become requirements for all modeling efforts. Respondents noted that model development efforts are not all the same. They differ in size, complexity, and level of the technology being applied. In addition, the contractual process as well as the contractual management relationship will vary from project to project. Respondents pointed to these structural and management differences as evidence of the need for flexibility in implementing any set of guidance factors. More specifically they noted the need to allow the manager freedom in determining which factors to consider and the level of activity required.

Survey responses prompted GAO to qualify its proposals for modeling guidelines:

> The guidance factors are not intended as absolute requirements. Rather, they represent a preliminary listing of procedures a manager should consider when undertaking a model development effort. These techniques are meant to provide the manager with an awareness of the total development process—not necessarily to establish a checklist for compliance. Most of the people we talked to stated that such guidance would be useful if it remained flexible.

Standards developed for use by a single organization are less likely to encounter objections. For example, the Corps of Engineers has established guidelines for models that are incorporated in the Corps' Engineering Computer Programs Library.[6] The stated objectives of the guidelines are to assure that models distributed through the library are: 1) immediately usable, broad in scope, easy to modify; 2) consistent with accepted engineering principles and practices; 3) uniformly and well documented; and 4) readily understandable by others and easy to set up and apply.

The standards specify the programing language to be used, and suggest specific programing practices that will enhance program usability. Detailed guidelines are provided for preparation of model documentation. Models that are incorporated in the library are placed in one of three categories, depending on the nature of the model and the level of review it has received. For example, a model in the highest category will have been designed for Corps-wide application, and will have received independent review and approval by the Corps' Office of the Chief of Engineers. A further discussion of Corps' procedures for developing and disseminating water resource models is included in the description of HEC in chapter 4.

Contractual Mechanisms

Numerous proposals have emerged for strengthening quality control by requiring the performance of certain procedures or the attainment of performance standards as part of the legal contract for developing a model. For example, developers might be required to provide specific levels of documentation acceptable to a review panel, or to achieve a specific level of accuracy before final payment on their contracts.

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[5] *Ways to Improve Management of Federally Funded Computerized Models*, U.S. Government Accounting Office, LCD-75-111, 1976.

[6] B. Eichert, "Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models," Technical Paper No. 56, Hydrologic Engineering Center, 1978.

Another GAO proposal called for Federal agency review of contractor performance at the end of each of five phases in developing models. Both the agency and the developer would have an opportunity to terminate the development process at the end of each phase:

> A contract with a breakpoint at the end of each phase should be used so that a developer cannot proceed from one phase to the next without written approval from the user. Each phase or breakpoint should be separately priced so that a termination at the end of a specific phase will limit the Government's liability under the contract to those costs incurred for the contractor's performance up to the breakpoint . . . . This gives the manager the opportunity to stop development if the model is not going to be useful.

Such procedures could increase an organization's control over ongoing model development projects, and, if properly managed, could offer incentives for developers to maintain professional standards and provide adequate user-oriented services. However, additional contractual specifications inevitably add to the complexity of monitoring model development.

Peer Review

Peer review procedures have been proposed as a means of identifying and promoting high-quality models without losing the flexibility required for innovative modeling. Review panels, composed of high-caliber professionals who are sensitive to the applications for which individual models are designed, could provide valuable advice to model developers, and assure sponsoring institutions of the value of the models they fund.

Opponents of the peer review approach cite the bureaucratic burden of establishing and maintaining review policies and procedures, and they question the relative value of the additional information as compared to its probable cost. These opponents also point out that seasoned modeling professionals are in relatively short supply—obtaining their services for a review panel on a continuing basis might be impossible. The use of less qualified reviewers for such a panel would reduce the weight and value of its recommendations.

Legal Aspects of Model Use in Administrative Processes

Models are often used to project the effect of a proposed administrative action. Managers employ model forecasts to minimize the possibility of causing costly errors or potential damages associated with inappropriate decisions. Major decisions involving millions of dollars may be based on model-generated information. If, for some reason, the models do not accurately simulate real conditions, administrative decisions based on model results could misdirect regulations, misguide management directives, and misallocate capital investments. Using models in regulatory processes raises the prospect that unforeseen errors may cause administrative actions to either fall short of their intended purpose or unreasonably burden those who are regulated.

Legal issues regarding the use of models in administrative processes have arisen in three areas: 1) standards for Federal judicial review; 2) judicial review of State-level regulations; and 3) use of models for planning and program development.

Standards for Federal Judicial Review

Although judicial consideration of water resource models dates back to a 1943 Supreme Court case involving an interstate dispute over water rights,[7] virtually all judicial notice has been in the context of recently promulgated water quality effluent limitations.[8] Courts have also examined water quality models that have been used as the basis for analyzing an environmental impact statement under the National Environmental Protection Act.[9]

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[7] *Colorado* v. *Kansas,* 320 U.S. 383 (1943).

[8] *Association of Pacific Fisheries* v. *E.P.A.*, 615 F.2d 794 (9th Cir., 1980); *Kennecott Copper* v. *E.P.A.* 612 F.2d 1232 (10 Cir., 1979); *BASF Wyandotte Corp.* v. *Costle,* 598 F.2d 637 (1st Cir., 1979); *National Crushed Stone Association* v. *E.P.A.* 601 F.2d 111 (4th Cir., 1979); *American Iron and Steel Institute* v. *E.P.A.* (11), 568 F.2d 284 (3rd Cir., 1977); *FMC* v. *Train,* 539 F.2d 973(4th Cir., 1976); *API* v. *E.P.A.*, 540 F.2d 1023 (10th Cir., 1976); *A.I.S.I.* v. *E.P.A.* (1), 568 F.2d 284 (3rd Cir., 1977).

[9] *Ohio Ex Rel. Brown* v. *E.P.A.*, 460 F. Supp. 248 (S.D. Oh., 1978); *Conservation Council of North Carolina* v. *Froehlke,* 435 F. Supp. 775 (M.D.N.C., 1977).

Models used for agency rulemaking are administrative actions reviewable by the courts.[10] The review standard is narrow:

> As in other cases involving review of an administrative agency's rulemaking actions we are governed by an "abuse of discretion" standard—in other words, we must not substitute our judgment for that of the agency, but must determine whether the administrator's actions were "arbitrary, capricious, are abuses of discretion, or otherwise not in accordance with law . . . ." In order to facilitate meaningful judicial review, we should require administrative agencies to "articulate the standards and principles that govern their discretionary decisions in as much detail as possible . . . ."[11]

Most courts reviewing models as a basis for administrative decisions rely on the standard set out in the U.S. Supreme Court case, *Citizens to Preserve Overton Park* v. *Volpe,*[12] that a court reviewing an agency's action should conduct a searching and careful inquiry into the facts, but should not substitute its judgment for that of the agency. The court held that the agency's use of the model should be accorded a "presumption of regularity."[13]

This judicial standard has significant implications for an agency's use of models in regulation, and grants broad discretion to the agency. When other models have been used to challenge an agency's model, the courts have examined only whether the agency's model constitutes a "rational choice."[14] Although judicial inquiry will include a thorough evaluation of a model, it does not extend to the determination of the "best possible approach."[15]

However, the documentation of the model must provide an "adequate explanation" of the basis for the regulation, absent which the court will overturn the regulation.[16] What constitutes "sufficient material upon which to make a reasoned decision," though, leaves a great deal of latitude to an agency.[17] Thus, there is a disinclination to "second guess the agency's expert determinations as to the model . . . ."[18]

Federal courts have proved relatively flexible in applying the "reasonable basis" test to disputed regulations. In a case where a model simplified the simulation of complex hydraulic flows in plastic manufacturing plants to the degree that the range of flows departed from the model's results by a factor of 10, the court found no reasonable basis for the challenged regulation.[19] In another instance, although the court heard arguments that the challenged model process differed from actual operation by a factor of 5, it sustained the contested regulation, being convinced that a reasonable explanation for the variation existed.[20]

The courts' reluctance to involve themselves in evaluating models per se is further illustrated by a case involving proprietary models. In *Cleveland Electric,* which challenged the imposition of a sulfur dioxide control plan based on the use of an EPA model, the agency's model was contested as inferior to a proprietary model developed by an engineering company.[21] Although expert witnesses testified that a superior method of control existed, the company refused to reveal the operating details of its model. As the court saw the problem:

> While such withholding may be both defensible as a matter of law and understandable as a matter of economics, this court cannot consider Enviroplan's model as available technology until and unless it is fully disclosed and evaluated by United States E.P.A.—the agency charged by Congress with making these decisions.[22]

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[10] The Federal Administrative Procedure Act provides that "except to the extent that—(1) statutes preclude judicial review; or (2) agency action is committed to agency discretion by law," 5 U.S.C. sec. 701 (a) (1976), "final agency action for which there is no other adequate remedy in a court (is) subject to judicial review." 5 U.S.C. sec. 704(1976). For a discussion, see, D. P. Currie, "Judicial Review Under Federal Pollution Laws," 62 *Iowa Law Review* 1221 (1977).

[11] *A.I.S.I.* v. *E.P.A.* (1), 526 F.2d 1027 (3d Cir., 1975).

[12] *Citizens to Preserve Overton Park, Inc.* v. *Volpe,* 401 U.S. 402 416 (1971).

[13] *Overton Park,* 401 U.S. at 415.

[14] *Cleveland Electric Illuminating Co.* v. *E.P.A.,* 572 F.2d 1150, 1161 (6th Cir., 1978), *cert. denied,* 439 U.S. 910 (1978); *U.S. Steel Corp.* v. *E.P.A.,* 605 F.2d 283, 292 (7th Cir., 1979).

[15] *Cleveland Electric,* 572 F.2d at 1150, 1161; *see also, Vermont Yankee Nuclear Power Corp.* v. *NRDC,* 435 U.S. 519, 549 (1977).

[16] *Kennecott Cooper* v. *E.P.A.,* 612 F.2d 1232, 1240 (10th Cir., 1979).

[17] *Association of Pacific Fisheries* v. *E.P.A.,* 615 F.2d 794, 803 (9th Cir., 1980).

[18] *Pacific Fisheries,* 615 F.2d at 810.

[19] *FMC Corp.* v. *Train,* 539 F.2d 973, 980 (4th Cir., 1976).

[20] *Pacific Fisheries,* 615 F.2d at 810, 814.

[21] 572 F.2d at 1163.

[22] Ibid.

Judicial Review of State-Level Regulations

Relatively few legal controversies have arisen over use of models by a State government as a basis for decisionmaking. The lack of reported cases may be partly attributable to a general lack of model use by States for regulatory purposes. Another reason may be the close link between Federal and State programs—such conflicts may arise in the context of the applicable Federal programs.

States have occasionally used models as evidence in administrative proceedings to determine whether a violation of an environmental control law has occurred; this is particularly true in the area of air pollution control.[23] For instance, the Illinois Pollution Control Board applied a "general theoretical formula" to the processing data of a smelting company to find the company in violation of air pollution standards. However, upon review, an Illinois court held that such modeling evidence was insufficient to support the board's determination.[24]

Litigation over regulations predicated on information from a ground water model occurred in the State of Washington in 1975. The State had developed a computer model for defining maximum rates of withdrawal and issuing new rights to ground waters. For the Odessa area, which had been declared a critical ground water region, the State issued regulations to establish ceilings on withdrawals with the assistance of the developed models.[25] Affected ground water users disputed the accuracy of the model results;[26] however, the courts upheld the regulation. Subsequent corrections to the model have altered model results, though not to the degree of affecting the regulation's efficacy in the eyes of State officials. Nonetheless, no further challenges to the regulation have been offered.[27]

Use of Models for Planning and Program Development

Probably in no other area is the use of models more prevalent than in planning and program development. However, errors in planning programs which are based solely on analysis by models can be perpetuated in decisions made on the basis of such plans. Mandated "consistency" requirements are potentially a major avenue for institutionalizing this kind of error.

For example, the Clean Water Act requires that the National Pollution Discharge Elimination System permits issued for point sources of pollution must not conflict with an approved section 208 areawide management plan.[28] In this manner, Congress established a "consistent" planning system, linking different elements to areawide planning under section 208. Consistency requirements also extend to construction of publicly owned treatment facilities, which must conform with the approved section 208 plan to be accepted.[29] Section 208 plans depend heavily on modeling. This statutory linkage between the areawide planning programs and regulation or construction activities raises the question of whether unforeseen modeling errors in plans may cause significant problems during implementation, and subsequently lead to litigation.

An important corollary to this issue is the question of a modeler's liability for the effects of inaccurate model results. No ruling yet exists on whether model use involves an express or implied guarantee that the operation of a system will substantially conform to model-generated information. If an individual or organization is placed in the position of certifying compliance with regulatory standards based on model results, whose responsibility is any subsequent nonattainment of such standards?

Absent any definitive ruling on the issue, new regulatory programs involving modeling and the use of highly sophisticated modeling analysis may increase the liability of the design professional. Similar problems have arisen over the professional liabilities of technically trained staff in other fields. The modeling community has already indicated its concern over exposure to liability in the context of certifying compliance with building energy performance standards under the Energy Conservation Standards for New Buildings Act of 1976.[30] [31]

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[23] For a discussion, see, R. A. Brazcuer, "Air Pollution Control; Sufficiency of Evidence of Violation in Administrative Proceedings Terminating in Abatement Orders," 48 *A.L.R. 3d* 795.

[24] *Allied Metal Co.* v. *Illinois Pollution Control Board,* 22 111 App. 3d 823,318 N.E.2 257, 264 (1974).

[25] G. E. Maddox, et al., "Management of Groundwater in Eastern Washington," Engineering, Geology, and Soils Symposium, 13th Annual Proceedings, University of Idaho, Moscow, Apr. 2-4, 1975, p. 201, published by Idaho Transportation Department, Division of Highways, Boise, 1975.

[26] Conversation with Alan Wald, Hydrologist, Washington Department of Ecology.

[27] Conversation with Charles Roe, Senior Assistant Attorney General, Washington Department of Ecology.

[28] Clean Water Act, sec. 208(e), 33 U.S.C. sec. 1288(e).

[29] Clean Water Act, sec. 208(d), 33 U.S.C. sec. 1288(d).

Increased use of complex modeling systems, and layered model use to develop State "equivalent" standards or programs under Federal mandates, may compound initially acceptable modeling errors, and also increase a modeler's potential liability.

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[30] Milt Lunch, "DOE's New BEPS Pose Many Legal, Liability Questions for Design Professionals," *Engineering Times*, April 1980; Statement of E. K. Riddick for the National Society of Professional Engineers on the Proposed Building Energy Performance Standards, Mar. 24, 1980, pp. 14-16.

[31] Testimony of D. Carter for the American Consulting Engineers Council, hearings before the Senate Governmental Affairs Committee, Nov. 20, 1979, p. 167.

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Chapter 4

Federal Use and Support of Water Resource Models

The Federal Government has a very broad range of water resource responsibilities. It is a major investor in facilities to control water supplies and treat polluted waters. It has taken the lead in programs to bring additional supplies to water-short areas of the country, and more recently to encourage more cost-effective approaches to water use in these areas. It has provided the legal and institutional framework within which States work to set water quality standards and ensure that they are met. Moreover, it is responsible for managing the water that flows through the 776 million acres of the country directly under Federal jurisdiction.

These responsibilities are expressed in numerous laws, and are administered by an array of Federal departments, agencies, and regulatory authorities. Water resource concerns touch virtually every aspect of the Nation's economic, social, and political well-being; thus, they are an integral part of the missions of many governmental institutions.

In analyzing Federal use of water resource models, the Office of Technology Assessment (OTA) collected and evaluated information from over 20 agencies and agency offices. Model use was examined by agency, by authorizing legislation, by resource issue, and by professional discipline.

ANALYSIS OF CURRENT FEDERAL MODELING CAPABILITIES

Methods Used to Survey and Analyze Federal Model Use

OTA used two primary approaches in soliciting information on Federal modeling efforts. It initially held a 2-day workshop for Federal modelers during October 1979, to determine their views on current major problems in Federal water resource modeling efforts. Attended by representatives from 21 Federal organizations, the workshop revealed significant institutional constraints to effective model development and use. In preparation for the workshops, each agency represented was requested to provide written responses to questions regarding its current use and development of models; critical problem areas, appropriate roles, and reasons for using models; anticipated future modeling needs; and current levels of monetary and personnel resources devoted to modeling.

At the workshop, modelers met in groups according to areas of professional expertise. Each group listed, discussed, and ranked the importance of its model-related concerns. Major findings from the workshop are summarized below; a more extensive summary of the Federal workshop, and of a subsequent workshop held for modelers from universities and the private sector, is presented in appendix A.

The second major component of OTA's information-gathering activity was a survey of the 22 Federal entities with substantive water resource responsibilities, conducted in June 1980. Each agency or office was requested to provide information on its model use under more than 20 major pieces of water resource legislation. Respondents were asked to specify legislatively assigned responsibilities, and areas in which models are employed, according to eight general use categories: 1) program planning; 2) promulgating regulations; 3) enforcing regulations; 4) complying with regulations; 5) planning or evaluating projects; 6) allocating funds; 7) technology transfer; and 8) operations and management. Statistical results of this survey are tabulated in table 3. Detailed descriptions of each agency's model use under specific laws and programs are

Table 3.—Federal Model Use by Program

	Section	Number of agencies with program involvement	Number of agencies using models to meet program responsibilities	Agencies using models to meet program responsibilities
Federal Water Pollution Control Act Amendments of 1972 (as amended by the Clean Water Act of 1977)				
Grants for pollution control program	106	2	0	
Mine water pollution control programs	107	2	2	FS, BM
Grants for construction of treatment works	201	5	4	ESCS, CORPS, USGS, EPA-OWRS
Areawide waste treatment management	208	7	6	EPA-OWRS, BR, FS, ESCS, SEA
Basin planning	209	9	7	BR, FS, EPA-OWRS, ESCS, NOAA, WRC, USGS
Water quality waivers	301	2	2	EPA-OWE, NOAA
Water quality-related effluent limitations	302	4	1	EPA-OWRS
Water quality standards and implementation plans	303	6	4	BR,FS, NOAA, EPA-SWER
Toxic and pretreatment effluent standards	307	8	2	EPA-OWRS, NOAA
Oil and hazardous substances liability	311	4	1	USGS
Clean lakes	314	6	3	FS, NOAA, USGS
Thermal discharges and exemptions	316	3	2	USGS, EPA-OWE
Guidelines and permits for dredged or fill material	404	7	1	USGS
Disposal of sewage sludge	405	7	1	ESCS
Safe Drinking Act				
Determining adverse health effects	1412	1	1	EPA-DW
Protection of underground sources of drinking water	1421	8	3	USGS, MINES, EPA-DW
Protection of sole-source aquifer systems	1424	1	1	EPA-DW
Surface impoundment assessment	1442	1	1	EPA-DW
State program grants	1443	1	1	EPA-DW
Special study and demonstration project grants	1444	5	1	USGS
Toxic Substances Control Act				
Testing of chemical substances and mixtures	4	4	1	EPA-PTS
Regulation of hazardous chemicals and mixtures	6	5	1	EPA-PTS
Resource Conservation and Recovery Act				
Solid waste management guidelines	1008	4	1	USGS
Identification and listing of hazardous wastes	3001	4	0	
Standards for owners and operators of hazardous waste treatment, storage, and disposal facilities	3004	7	0	
Consolidated permits for hazardous waste management facilities	3005	5	0	

Table 3.—Federal Model Use by Program (Continued)

	Section	Number of agencies with program involvement	Number of agencies using models to meet program responsibilities	Agencies using models to meet program responsibilities
Grants for State resource recovery and conservation plans	4008	1	0	
Full-scale demonstration facilities grants	8004	1	0	
Resource recovery system and improved solid waste	8006	3	1	USGS
Endangered Species Act				
Minimizations of impacts of Federal activities modifying critical habitats	7	9	3	BR, FS, FWS
Surface Mining Control and Reclamation Act				
Surface coal mine reclamation permitting	506	6	3	FS, USGS, OSM
Permit approval or denial	510	1	1	OSM
Enviromental protection performance standards for surface coal mine reclamation	515	6	4	FS, USGS, BM, OSM
Soil and Water Resource Conservation Act of 1977				
Data collection about soil, water, and related resources	5	6	2	FS, USGS
Soil and water conservation programs	6	7	5	FS, ESCS, NOAA USGS, BM
Water Resources Planning Act				
Regional or river basin plans and programs and their relation to larger requirements	102	10	7	BM, BR, ESCS, CORPS, NOAA, USGS, WRC
Coordinating Federal water and related land resources programs and policies	102	7	2	USGS, BM
Assessemnt of the Nation's water resources conditions	102	1	1	WRC
Coastal Zone Management Act				
State coastal zone land and water resources management program development and management grants	305	6	2	NOAA, USGS
Executive Order 11988				
Flood plain management	2 & 3	9	5	FS, CORPS, USGS, WRC, NRC
Flood Control Act of 1936 and Amendments				
Flood control structures	1,2,3,	7	5	BR, FS, CORPS, NOAA, USGS
National Flood Insurance Act of 1968				
Identification of flood-prone areas	1360	2	2	FEMA, SCS
Federal Reclamation Act of 1902 and Amendments				
Irrigation distribution systems	(43U.S.C.421)	5	3	USGS, FS, BR
Construction of small projects	(43U.S.C.422)	3	1	FWS
National Environmental Policy Act				
Administration; EIS review and comment	102,103	5	5	BR, FS, CORPS, NOAA, NRC

Table 3.—Federal Model Use by Program (Continued)

	Section	Number of agencies with program involvement	Number of agencies using models to meet program responsibilities	Agencies using models to meet program responsibilities
Atomic Energy Act of 1954				
Flood protection of nuclear facilities	10 CFR 50	1	1	NRC
Water supply for nuclear power facilities	10 CFR 50	1	1	NRC
Limitation of radioactive liquid to ground and surface water	10 CFR 20, 50, 61	2	2	NRC, USGS
Fish and Wildlife Coordination Act				
Consultation and provision of recommendations; surveys and investigations	182	2	2	FWS, NOAA
Colorado River Basin Salinity Control Program	10, 201, 202, 203	2	2	BR, SCS

Agency abbreviation key:

ASCS — Agricultural Stabilization and Conservation Service
CORPS — Army Corps of Engineers
BM — Bureau of Mines
BR — Bureau of Reclamation
DOE — Department of Energy
EPA — Environmental Protection Agency
  DW — Office of Drinking Water
  OWE — Office of Water Enforcement
  OWRS — Office of Water Regulations and Standards
  SWER — Solid Waste and Emergency Response Program
  PTS — Pesticides and Toxic Substances Program
ESCS — Economics and Statistics Cooperative Service
FEMA — Federal Emergency Management Agency
FS — Forest Service
FWS — Fish and Wildlife Service
NOAA — National Oceanic and Atmospheric Administration
NRC — Nuclear Regulatory Commission
OSM — Office of Surface Mining Reclamation and Enforcement
SCS — Soil Conservation Service
SEA — Science and Education Administration
USGS — U.S. Geological Survey
WRC — Water Resources Council

Table 4.—Agency Estimates of Fiscal Year 1979 Expenditures for Water Resource Models and Related Activities (in millions of dollars)

U.S. Geological Survey:	
Research	3.0—4.0
Application	12.0—15.0
Army Corps of Engineers	6.5—7.7
National Science Foundation	2.8
National Oceanic and Atmospheric Administration	2.8
Department of Energy	0.9—1.1
Department of Agriculture	0.7[a]
Department of Interior	4.7—5.9
Environmental Protection Agency	7.8—9.4
Total	40.2—49.4

[a] Includes estimates only from SCS and ESCS.

SOURCE: Developed from information provided in agency responses to OTA questions regarding model use, October 1979, and from a June 1979 telephone survey of selected Federal agencies. Figures include expenditures for both research and application.

provided in appendix B. Insofar as OTA has been able to ascertain, no previous governmentwide compendium of water resource model use and application has been attempted.

These information-gathering activities were supplemented by OTA-commissioned reports on model uses, limitations, and appropriate roles in four broad water resource areas, and by telephone surveys regarding costs associated with modeling activities for fiscal year 1979. Estimates of fiscal year 1979 expenditures for water resource models are provided in table 4. OTA has also relied on previously published studies of Federal, Canadian, and international model use to corroborate its general findings. Five of the most relevant studies are summarized in appendix C; individual references to these findings are also made throughout this chapter.

Findings From the Federal Agency Survey

Table 3, which summarizes agency model use by law, and compares areas of responsibility to areas in which models are employed, provides a general indication of current patterns of Federal water resource activities and model use. As might be expected, the more comprehensive the scope of a water resource-related law, the greater the number of agencies whose missions are affected by it. The widest-ranging of current water resource laws, the Clean Water Act of 1977, involves about 15 agencies and offices, which are assigned various responsibilities under or must comply with regulations stemming from 14 different sections of the law. Twelve agencies or offices indicated model use under this act. Some laws, such as the National Flood Insurance Act of 1968 (Public Law 90-448), are the responsibility of a single agency—in this case, the Federal Emergency Management Agency. On the whole, however, most pieces of Federal legislation affect more than a single agency, office, or regulatory authority.

None of the laws identified in the Federal agency survey specifically require the use of models to analyze a water resource issue. However, many of the analytic responsibilities specified in the legislation are routinely carried out with models. Under the Forest and Rangeland Renewable Resources Act of 1974 (Public Law 93-378), for example, the Forest Service of the U.S. Department of Agriculture (USDA) is charged with developing and implementing long-range land and resource management plans for the federally owned forests under its jurisdiction. It uses models that assess the effects of different management practices on water supply, water quality, other significant natural resources, and local economic activity. The information generated by these models is used in determining National Forest Management Act Regulations.

Much of the current Federal legislation directs individual agencies to determine standards that may

Photo credit: Environmental Protection Agency

Models are employed in fulfilling a wide variety of Federal water resource management responsibilities, and their use is expected to grow substantially in the future. Day-to-day operation of many Federal water projects, such as the Grand Coulee Dam in the State of Washington, increasingly involves extensive model use affect the program responsibilities of other agencies. Under the Clean Water Act (Public Law 95-217), the Safe Drinking Water Act (Public Law 93-523), and the Toxic Substances Control Act (Public Law 94-469), the Environmental Protection Agency (EPA) regulates and sets allowable concentrations for a number of toxic substances, organic chemicals, pesticides, and other residuals. A variety of models are used to determine how these substances are transported to and within receiving waters, and to estimate their effects on human and aquatic populations. Such regulations must subsequently be incorporated into analyses performed by various agencies of USDA and the Bureau of Mines, land and forest management practices of the Department of the Interior (DOI) and the Forest Service, and permitting processes of the Nuclear Regulatory Commission for thermal effluents, among others.

The findings outlined in table 3 reflect a highly uneven pattern of Federal model use for water resource analysis. While some agencies use models to analyze a particular resource issue throughout the range of their statutorily assigned program responsibilities, others use them only for a particu lar responsibility (e.g., complying with regulations), and still others rely solely on noncomputerized analytical approaches. These inconsistencies cause such problems as inconsistent flood plain delineations by different agencies, confusion over best management practices for controlling nonpoint source pollution, and disputes over projections of the amount of water available for energy development in the Western United States. Further, while highly efficient model-based management techniques have been developed in several Federal agencies (e.g., for operating reservoirs), many agencies do not benefit from this already-developed expertise.

A number of factors underlie agency decisions regarding model use. Developing a model is an expensive and technically complex undertaking, involving highly specialized personnel requirements, extensive computer facilities, and appropriate data bases. If the problem to be analyzed is not *directly* related to the agency's mission, the agency will often be reluctant to commit the resources necessary to develop a model to address the problem.

Moreover, substantial difficulties often deter agencies from adapting models that have already been developed elsewhere in the Federal Government. When practicable, model adaptation permits significant cost-savings, although adequate data bases and computer facilities, in addition to technical assistance in adapting the model, are still necessary. However, information about the availability of many existing Federal models is not readily obtainable. Few agencies have taken steps to disseminate information on the models they have developed. In addition, Federal models are often so poorly documented that a manager cannot determine their suitability for use by his agency.

Findings From the Federal Workshop

Although Federal agency modelers met and discussed issues in four separate professional groupings—1) surface water flow and supply; 2) surface water quality; 3) ground water; and 4) economic/social—the majority of their concerns were not specific to these areas, but encompassed the broader problem of providing adequate and appropriate institutional support for modeling activities in general. Indepth summaries of modelers' deliberations on such issues as research and development (R&D) needs, data needs, documentation, validation, technology transfer, model maintenance, the utility of model clearinghouses, and interagency coordination, are provided in appendix A.

Participants ranked the following issues as being among the most significant of those discussed:

- collecting accurate and adequate data to develop, test, and apply models;
- improving decisionmaker understanding of general capabilities and limitations of models;
- improvements in user support, training in model use, and analysis of results;
- greater emphasis on documentation of models;
- improved planning and resources for model maintenance and management;
- making federally developed models known and available to other Federal agencies and to the public; and
- improving coordination among agencies for model development and use.

The significance of these issues to water resource analysis and problem-solving capabilities at the Federal level is discussed below.

Data Availability

The availability of sufficient data to characterize a physical system is critical to modeling it successfully. Computer models are often highly data intensive, requiring independent data sets for development, calibration, verification, and application phases. Workshop participants pointed to the expense of collecting water resource data as a major limiting factor in constructing models.

Most existing Federal data bases are created to serve program purposes rather than for research and analysis per se. Developers consequently find much of the existing data unsuitable for modeling activities. Participants suggested coordinated approaches to data collection and model development, as well as sensitizing model developers to the potential data requirements (and costs) of their models. Emphasis was also placed on the need to improve access to existing data bases, and improve the cost effectiveness of future data collection efforts, particularly through interagency coordination and data base consolidation.

Coordinating and integrating data collection on a governmentwide basis is a major Federal management issue, and concerns many informational purposes in addition to modeling efforts. Consequently, an indepth analysis of Federal data-gathering activities is beyond the scope of this report. However, results from the OTA workshop and surveys, as well as surveys of federally developed models by the National Science Foundation (NSF)[1] and the General Accounting Office (GAO),[2] indicate that modelers and managers alike consider problems in obtaining data to be the most prevalent limitation on model development efforts. Three of the four OTA workshop groups considered this to be their top priority concern, while respondents to the GAO survey attributed one-fifth of all identified modeling problems to data availability. Any future attempts to improve Federal data-gathering practices and procedures will have major effects on the modeling community. Input from this community should be solicited in data collection planning to minimize additional data-gathering costs associated with future modeling efforts.

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A field researcher measures streamflow in fast-moving currents. Resulting data may be useful for many modeling purposes if they can be made readily available to interested users

Improving Decisionmaker Understanding of Models

Information gaps between decisionmakers and modelers were among the top three priority concerns for all four modeling groups at the OTA Federal workshop. Workshop participants focused on the relationship between modeling and the decisionmaking process as a major deficiency in current Federal modeling practices. Upper-level managers were characterized as being unaware of basic modeling concepts and of the limitations and capabilities of the specific models they use. Modelers pointed to a lack of mechanisms throughout the Federal Government for bringing managers and modelers together to plan and develop models. Such a lack of interaction was seen as a major contributor to management-level mistrust of models, and the inadequacy of current levels of support for planning long-range model development, documenting and maintaining models, and providing user services.

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[1] Gary Fromm, William L. Hamilton, and Diane E. Hamilton, *Federally Supported Mathematical Models: Survey and Analysis,* under contract with the Division of Social Systems and Human Resources of the National Science Foundation, June 1974.

[2] *Ways to Improve Management of Federally Funded Computerized Models,* General Accounting Office, August 1976.

These findings are strongly in accord with those from earlier studies. The survey of 222 nondefense Federal models conducted in 1974 for NSF found highest rates of failure in modeling projects designed to provide information to policymakers. The low utilization rate of such models was attributed primarily to lack of communication between model builders and potential policymakers during model development, and secondarily to policymakers' limited understanding of models that had already been developed.[3] Similarly, one-fifth of modeling problems identified in the GAO survey (1976) were attributed to "lack of management acceptance and knowledge of modeling techniques."[4]

Integrating the needs of decisionmakers into model development processes is especially critical if models are to be used effectively at agency decisionmaking levels. Federal managerial personnel often have a great deal of discretion over what procedures to employ in analyzing an issue. Some may have obtained favorable results from modeling in the past, while others may have been "burnt" by relying on the accuracy of model-based information. Since the Federal Government provides no guidelines regarding model uses for analytical purposes, and offers very little management-level education in model use and interpretation, decisionmakers are generally "on their own" in deciding when to commit their agencies to modeling efforts.

In practice, Federal agencies tend to commission models in response to a specific problem, when a decisionmaker becomes aware of the need for otherwise unavailable information. All too frequently, however, Federal modelers are given little instruction regarding the nature of the desired information, and are not provided access to the individual(s) who must act on the information generated. Technically sophisticated, yet impractical models often result, and are quickly abandoned to agency archives.

User Support

Participants in the OTA modeling workshop frequently asserted that Federal modeling efforts have overconcentrated on model development, and devoted inadequate resources to transferring modeling technology and expertise to potential users. All four workshop groups placed some aspect of user services among their top three priorities. Many participants stated, however, that current agency career evaluation systems discourage modelers from providing such technology transfer to model users. While incentives are provided for developing increasingly sophisticated models, no incentive structure currently encourages modelers to aid users in understanding, running, and interpreting the results of such tools.

Workshop participants singled out three major aspects of technology transfer as needing additional attention and resources: 1) documentation; 2) training in model use and interpretation; and 3) technical assistance. Most participants appeared to consider *documentation* the most critical of technology transfer needs. Because documentation is time consuming and expensive to produce, decisionmakers and modelers alike have tended to assign it low priority, concentrating on the production of "bottom-line" information. Without adequate documentation, however, decisionmakers cannot subsequently determine how the information was generated, nor evaluate it. Documentation is also crucial for providing individuals in other Federal agencies a means of determining whether they can use a previously developed model. A 1974 GAO survey of 710 Federal data-processing personnel and auditors who reported problems due to inadequate documentation, revealed that nearly one-third (233) of the related programs had to be totally rewritten, and one-sixth (127) of the automated data-processing systems had to be redesigned. Moreover, more than half (428) of the documentation-related problems resulted in substantial delays in the completion of assignments.[5]

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[3] Fromm, Hamilton, and Hamilton, op. cit., pp. 3-7, 51-54.

[4] General Accounting Office (1976), op. cit., p. 37.

[5] *Improvement Needed in Documenting Computer Systems*, General Accounting Office, October 1974, pp. 6-7.

Concern over the inadequacy of current levels of documentation for Federal models is corroborated by the 1974 NSF survey, and by a 1979 survey of 39 modelers conducted for the National Bureau of Standards (NBS). NSF found that for about 75 percent of the 222 surveyed models, the documentation supplied by the developer was inadequate to enable nonproject personnel to set up and run the model.[6] Developers surveyed by NBS showed strong support for governmentwide model documentation guidelines, including the specification of a documentation plan in model development contracts, detailing the documents to be produced, the resources allocated, and personnel responsibilities.[7]

Training opportunities are essential to developing in-house capabilities for running and interpreting models. Unless training is supplied, agencies are totally dependent on model developers for model-generated information. The 1974 GAO survey found the third-largest source of major modeling problems to be "lack of qualified personnel to operate and maintain the model." Workshop participants were similarly concerned to find ways of encouraging agencies to provide adequate resources for model-related training. Different levels of training for decisionmakers and for users were repeatedly advocated, the latter type to incorporate "hands-on" interaction with the model and "one-on-one" instruction where possible.

Workshop participants also pointed to the routine provision of *technical assistance* as an inexpensive means of troubleshooting in model use. The availability of knowledgeable individuals to answer simple "over-the-phone" questions can save man-hours and computer time that are otherwise lost to trial-and-error attempts to operate the model. For more complex models and/or modeling problems, participants suggested temporarily assigning developers to user organizations to facilitate the initial setting-up of the model.

Maintenance and Dissemination

The current structure of Federal modeling activities gives agencies little incentive to consider potential uses for models once they have served the agency's primary purpose. Consequently, most models are not updated, or maintained, to keep them technologically current, nor is information about their existence or availability circulated among potential users in government and the private sector. One of the most frequently voiced concerns of workshop participants was the difficulty of locating and obtaining existing Federal models. Many modelers considered improving access to current models a higher priority than improving and developing new ones. Participants generally agreed that lack of information regarding the availability of Federal models is a significant barrier to their widespread use.

Participants also noted the Federal Government's lack of commitment to maintaining the models it has already developed. They stressed the need to develop mechanisms and/or organizational units with routine responsibilities for periodic model analysis and updating. The need to inform model users of changes made to a model was also considered to be neglected in current agency procedures.

Interagency Coordination

Federal modelers identified the lack of interagency coordination as a major bottleneck in efforts to advance the state of the modeling art. Managers tend to be unaware of the modeling and model development projects being supported by other agencies, a situation that may lead to decisions to build models already in existence or in process of development. A certain amount of duplication in modeling has potentially beneficial effects—it fosters a kind of competition from which more accurate and efficient modeling techniques can result. However, for highly complex modeling tasks, interagency pooling of resources and technical expertise could facilitate greater and more rapid advances than are possible when each agency functions independently. As explained in a USDA Soil Conservation Service background paper for the OTA modeling workshops, "There would be value in encouraging broader use of certain water resource models among

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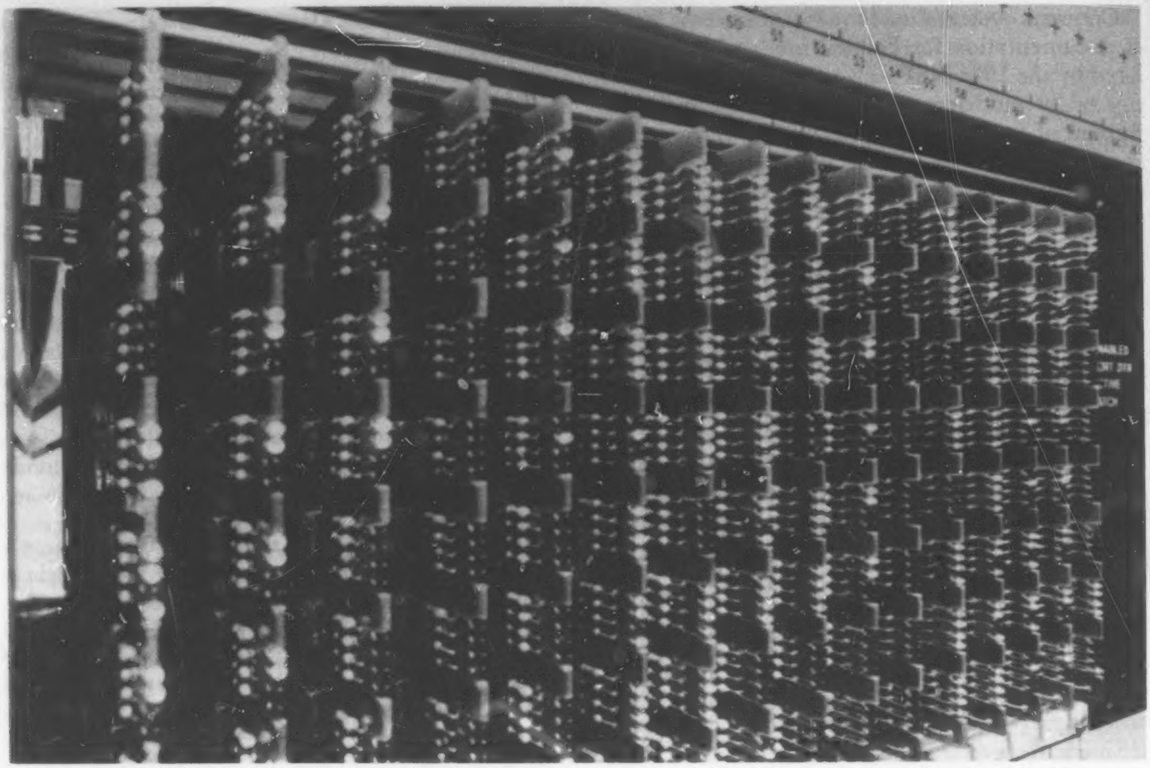
[6] Fromm, Hamilton, and Hamilton, op. cit., p. 6.

[7] Saul I. Gass, "Assessing Ways to Improve the Utility of Large-Scale Models," in *Validation and Assessment Issues of Energy Models*, National Bureau of Standards, Special Publication 569, February 1980, p. 251.



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Federal agencies with modeling expertise and computing facilities provide extensive assistance to State and local users, as well as to users in other Federal offices. Miniature lights on these panels at USGS computer facilities in Reston, Va., glow when telephone hookup lines to computers are currently in use

Federal agencies both to reduce duplication of modeling effort and to obtain the benefit of multiple agency comment following their use."

Further, for highly complex and interdisciplinary modeling, interagency participation may be the only means of assuring that high-quality models are brought to completion. The creation of adequate data bases to support sophisticated modeling projects, in particular, calls for interagency coordination and planning.

CURRENT APPROACHES TO FEDERAL MODEL MANAGEMENT

This section reviews the Federal legislation and program activities that affect the development and use of water resource models. It analyzes the planning framework through which funding is provided for model-related work. This section further describes the major organizational and institutional arrangements currently responsible for disseminating water resource models and/or assisting other water resource agencies to use them. Because modeling is an integral part of Federal responsibilities for water resource analysis, data collection, and R&D, this section also addresses a number of Federal agencies and offices for which the advancement of modeling capabilities is not a primary objective. The section is organized according to four major areas of Federal involvement: 1) governmentwide water R&D policies; 2) governmentwide coordination and dissemination activities; 3) agency-level modeling activities; and 4) agency-level dissemination activities.

Consideration of Models in Governmentwide Water R&D Policies

The Water Research and Development Act of 1978

The Water Research and Development Act of 1978 is currently the major legislative mechanism for coordinating the development of analytical tools to address water resource issues. It states the congressional finding that "the Nation's capabilities for technological assessment and planning and for policy formulation for water resources must be strengthened at both the Federal and State levels," and assigns responsibilities to the President and the Secretary of the Interior for developing a coordinated Federal program of water-related research and technology.

The act directs the President to:

> Clarify agency responsibilities for Federal water resources research and development and provide for interagency coordination of such research, including the research authorized by this Act. Such coordination shall include: 1) continuing review of the adequacy of the Government-wide program in water resources research and development and identification of technical needs in various water resources research categories, 2) identification and elimination of duplication and overlaps between two or more programs, 3) recommendations with respect to allocation of technical efforts among the Federal agencies, 4) review of technical manpower needs and findings concerning the technical manpower base of the program, 5) recommendations concerning management policies to improve the quality of the Government-wide research effort, and 6) actions to facilitate interagency communication at management levels (sec. 406(b)).

In addition, the act assigns specific responsibility to the Secretary of the Interior to:

> Develop a five-year water resources research program in cooperation with the (state water research) institutes and appropriate water entities, indicating goals, objectives, priorities, and funding requirements (sec. 103 (b)).

To fulfill these objectives, and other objectives of the act:

> The Secretary shall cooperate fully with, and shall obtain the continuing advice and cooperation of, all agencies of the Federal Government concerned with water problems, State and local governments, and private institutions and individuals, to assure that the programs conducted under this Act will supplement and not duplicate other water research and technology programs, will stimulate research and development in neglected areas, and will provide a comprehensive, nationwide program of water resources research and development (sec. 406 (a)).

In assigning responsibility for developing a comprehensive 5-year water resources research program to the Secretary of the Interior, the act broadly outlined a new mechanism for coordinating Federal water resources analysis. Between 1963 and 1977, such a task had been the responsibility of the Committee on Water Resources Research (COWRR), under the aegis of the Federal Council for Science and Technology within the Executive Office of the President (EOP). Beginning in 1966, COWRR developed and annually updated a long-term program for water resources research. Its reports recommended priority research areas and were intended to guide Federal agencies in allocating research funds.

The 1978 act calls, in general terms, for EOP to play a lead role in coordinating the conduct of water resources analysis among the Federal agencies, relying on DOI to develop a research and technology agenda as a basis for EOP decisions. President Carter's message on science and technology, delivered to the Congress on March 27, 1979, further directed the Secretary of the Interior and the Director of the Office of Science and Technology Policy (OSTP) to determine research priorities for meeting the Nation's long-range water needs.

Development of the Five-Year Water Resources Research Program

Under the joint direction of DOI and OSTP, interagency policy and working groups summarized current agency-level programs of water reseach and short-term priorities in "Water Research Priorities for the 1980's" (April 1979),[8] and developed recommendations for improving the Federal effort in 10 broad subject areas in "Interim Report—Priorities in Federal Water Resources Research" (August 1979).[9]

"Proposed U.S. National Water Resources Research, Development, Demonstration, and Technology Transfer Program, 1982-87, draft,"[10] an expanded version of the agency summaries with projected funding levels for fiscal years 1982 to 1987, was delivered to the Water Resources Research Review Committee of the National Academy of Sciences (NAS) for review in December 1980. The NAS evaluation, *Federal Water Resources Research: A Review of the Proposed Five-Year Program Plan,*[11] was published in May 1981.

Water resources models figure prominently in the description of agency research efforts in the April 1979 and December 1980 documents. The extent of the Federal commitment to modeling activities is exemplified by frequently occurring references to them in many of the agency reports. EPA, for example, lists among its research priorities the need to:

> . . . develop, test and validate models for simulating source loads and "in-stream" processes for use in assessing water quality problems, allocating source loads, and evaluating alternative management strategies; and expand modelling capability to include toxics, especially with regard to sediment processes.[12]

Agencies also report needs for information and models in areas where, lacking authorization to fund model development, they must rely on the modeling effort of other agencies. The Soil Conservation Service of USDA pointed out the need "to improve estimates of erosion potential and nutrient loss from forest and rangelands;[13] similarly, the Department of Transportation stated that it could benefit from work to "develop operational two-dimensional model simulating stream degradations, aggradation, and local erosional processes."[14]

Both documents are compendiums of individual agency research plans; consequently, opportunities for interagency coordination of modeling efforts, or other research and technology-related activities, are not addressed. In addition, neither document describes agency activities in sufficient detail to permit a determination of levels of funding allocated to modeling activities, or the means used to coordinate modeling and related support efforts within each agency. No summary of State needs was included in either document, and it is difficult to determine how or whether the State water resources research institutes' 5-year programs were considered in formulating the agency research plans that constitute the December 1980 draft.

The "Interim Report" of September 1979 sets out goals and general priorities for governmentwide water resources R&D. It indicates many areas in which improved modeling capabilities are needed, including conjunctive ground water/surface water systems, aquatic ecosystems, environmental impacts to wetlands, chemical transport, verification of water quality and wasteload allocation models, flood plain delineation, streamflow forecasting, and hydrological/meteorological forecasting. No attempt is made, however, to relate general goals to specific agency activities, or to recommend divisions of responsibility and funding allocation levels among agencies. The report provides broad guidelines to agencies conducting research and analytical activities, but addresses none of the management concerns outlined in the 1978 act.

The differences between the two agency compilations and the "Interim Report" suggest one of the major difficulties in creating an overall Federal strategy for water resources R&D. From the perspective of each Federal agency or program, models and research are valuable primarily for their contribution to specific program objectives. Alternatively, an overview of national water resource problems can show areas in which lack of computer-based information prevents important advances in identifying needs, creating cost-efficient control strategies, and developing better administrative and legislative tools. Making agencies more responsive to such national-level concerns requires concerted, ongoing efforts at highest management levels to integrate overall objectives into routine agency decisions and funding allocation procedures.

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[8] "Water Research Priorities for the 1980's," Department of the Interior, Office of Water Research and Technology, April 1979.

[9] "Interim Report—Priorities in Federal Water Resources Research," Department of the Interior and the Office of Science and Technology Policy, August 1979.

[10] "Proposed U.S. National Water Resources Research, Development, Demonstration and Technology Transfer Program, 1982-1987, Draft," Department of the Interior, December 1980.

[11] *Federal Water Resources Research: A Review of the Proposed Five-Year Program Plan,* Water Resources Research Review Committee of the National Research Council (Washington, D.C.: National Academy Press, 1981).

[12] "Water Research Priorities for the 1980's," p.67.

[13] Ibid, p. 9.

[14] Ibid, p. 63.

The NAS evaluation of the proposed 5-year program plan also sets out to define broad problem areas in which further water resources research is needed. It focuses, however, on analyzing inadequacies in the December 1980 draft, and identifying institutional constraints to the development and implementation of a coordinated long-range Federal plan. The NAS study points out the inadequacies of a focus on research per se—rather than on a broader range of analytical and support needs—as a major defect in the DOI/OSTP coordinating effort.

> The report by its title purports to cover more than "water research"—namely, "development, demonstration, and technology transfer," although these terms are not defined. Rigorous attention is not given to distinguishing those separate activities in the program statements of the individual agencies, and no overall assessment of these activities is included in the program. The instructions to the agencies mentioned only research.[15]

The NAS study further concludes that the directives of the 1978 act are insufficient in themselves to provide a basis for coordinated Federal approaches to water resource R&D.

> The deficiences noted in the draft of the five-year program report are convincing evidence that the ad hoc approach to management of the Federal water research program will not yield the results expected by Congress when it enacted the Water Research and Development Act of 1978.[16]

OTA's survey of Federal water resource modelers and of related studies suggests that directives for formulating an overall Federal plan for water research and technology should specifically address the relationship between research and developing usable analytic tools. Priorities and allocation of funding and manpower need to be set for both kinds of activities, as well as for mechanisms to transfer modeling expertise and increase model availability to Federal, State, local, and private sector users.

Role of the State Water Resources Research Institutes in Coordinating Federal Water R&D Policy

The Water Resources Research Act of 1964, and its successor, the Water Research and Development Act of 1978, provided for the establishment of a network of State water resources research institutes at a designated land-grant college or university in each State.[17] Under the auspices of the Office of Water Research and Technology (OWRT) in DOI, the institutes have funded a wide variety of research programs in water resources. Since its inception, the State Institute Program has involved over 35,000 professionals and students in water-related research and problem-solving studies. Funding has been provided by OWRT on a matching basis with State governments under two separate programs: 1) a basic allocation of $110,000 per State (as of fiscal year 1980), and 2) a competitive grants program allotting a total of over $5 million (as of fiscal year 1980). However, for fiscal year 1982, the competitive grants program has been eliminated, while the basic allocation to individual States has been reduced to the $110,000 1980 figure. In addition, OWRT has been scheduled for elimination, and its duties and responsibilities transferred to other offices and programs, before the end of the current fiscal year.

The State Institute Program has proved to be an efficient, effective means of encouraging a wide variety of water research efforts. In fiscal year 1979, the latest year for which detailed cost statistics are available, total Federal support of slightly over $21 million elicited a nearly equal commitment of State and private funds. During that year, the program supported the work of about 1,200 principal investigators and about 1,750 student research assistants. Modeling activities constitute an important component of institute efforts, and increased training opportunities in model-related skills for water resource professionals have been one of the program's major byproducts.

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[15] *Federal Water Resources Research,* op. cit., p. 45.

[16] Ibid, p. 58.

[17] There are currently 54 institutes—one per State, and additional institutions in Washington, D.C., Puerto Rico, Guam, and the Virgin Islands.

The 1978 act also designates the institutes as the principal source of information regarding State water research needs for use in creating the Federal 5-year program plan. Each institute is required to submit to the Secretary of the Interior for approval an annual program "developed in close consultation and collaboration with leading water resources officials within the State" and "to cooperate with the Secretary in the development of five-year water resource research and development goals and objectives."

The scope of institute activities varies greatly from State to State. Some institutes focus on analytical work in cooperation with State water agencies; others concentrate on more traditional research functions. The diversity of the activities and concerns of the 54 State institutes is highly appropriate to their research missions, but has mixed implications for relaying State agency needs in water resource R&D to Federal policymakers. The institutes are closely connected to the academic institutions at which they are housed, and are not alined with any one State agency. Their freedom from mission-oriented concerns and priorities gives them the potential to represent the needs of all the State-level water resource agencies. However, since the institutes are staffed primarily by research scientists with professional ties to universities, they are not involved with day-to-day State agency problems.

Existing Governmentwide Mechanisms for Coordinating Modeling and Model-Related Information

Office of Water Data Coordination (OWDC)

Since water resource modeling tends to be highly data-intensive, model developers and users are particularly vulnerable to problems of data availability. Unless the collection of required data can be planned simultaneously with model development, modeling activities must be adjusted to the available data resources. This makes coordination of water data collection extremely important to successful use of water resource models.

Hydrologic data are collected by a large number of governmental and private entities, normally in order to serve some specific informational purpose or in support of established program activities. Historically, such data were collected under methods and standards devised to suit an organization's or agency's individual purposes, and were stored away once the organization's needs for it were met. While some general-purpose data on the quality and quantity of the Nation's available water resources were routinely collected and disseminated by the Water Resources Division of the U.S. Geological Survey (USGS), potential users of water data frequently encountered difficulty in identifying and locating existing data bases. Afterwards, even when such data were located, they were often found unusable, due to collection methods and/or standards of accuracy that failed to meet user requirements.

In 1964, to aid in coordinating water resource data, the Office of Management and Budget (then the Bureau of the Budget) issued Circular A-67, assigning the role of lead agency for such activities to DOI, which assigned specific responsibility for this function to USGS. To carry out this responsibility, USGS created OWDC, and gave it the following principal responsibilities:

- exercising leadership in achieving effective coordination of water data acquisition activities;
- undertaking continuing and systematic review of water data requirements and activities;
- preparing and keeping current a *Federal Plan* to aid in coordinating agency water-data acquisition efforts;
- maintaining a central Catalog of Information on Water Data and on Federal activities being planned and conducted to acquire water data; and
- designing and operating a national network for acquiring data on the quality and quantity of ground and surface waters, including the sediment loads of streams.

Major programs of OWDC most relevant to modeling needs include:

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Photo credit: © Ted Spiegel, 1982

Banks of disk-drive units retrieve and store information at USGS headquarters in Reston, Va.

Federal Plan.—A key coordination document, summarizes the plans and needs of agencies acquiring or using water data.[18] It brings these plans together at the level of each of the 21 national regions of the Water Resources Council—the regional plans are then assembled as the basis for the unified Federal Plan. Ongoing field-level review and Interagency Advisory Committee oversight are employed to achieve coordination at local and national levels.

Catalog of Information on Water Data.—A computerized file of information about water data activities. Currently, the catalog is divided into four sections: 1) streamflow and stage; 2) quality of surface water; 3) quality of ground water; and 4) aerial investigations and miscellaneous activities. Special indexes such as the four-volume "Index to Stations in Coastal Areas" have also been published. Another special index currently being prepared covers water data acquisition activities in the major coal provinces of the United States.

National Water Data Exchange (NAWDEX).—A national confederation of water-oriented organizations working together to improve access to water data. Developed by a working group of the Interagency Advisory Committee on Water Data, it has a function which the Catalog of Information on Water Data only partially fulfills—that of assisting users of water data in identifying, locating, and acquiring needed data. NAWDEX members are linked so that their several water data holdings may be readily exchanged for maximum use. Coordination and overall management for the program is provided by a central program office within the Water Resources Division of USGS.

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[18] "Plan for Water Data Acquisition by Federal Agencies Through fiscal year 1982," Office of Water Data Coordination, USGS, Department of the Interior, August 1980.

Water Resources Scientific Information Center (WRSIC)

An early priority of COWRR was the establishment of a central facility to collect and disseminate information relating to water resource analysis. In response to its recommendations, under the authority of the Water Research and Development Act of 1964, DOI created WRSIC within OWRT (then the Office of Water Resources Research) in 1966.

WRSIC is primarily a management and support unit that funds the compilation of information by other organizations. It does not collect and store published material, nor does it have a staff of abstractors, indexers, and support technicians. It contracts with a variety of governmental and private organizations to collect information under service and funding agreements, and produces publications and computerized records by arrangement with additional government organizations. Its two major information systems have been the *Selected Water Resources Abstracts* (SWRA) and the Water Resources Research in Progress File. Recent budget reduction initiatives have cut WRSIC appropriations from over $900,000 for fiscal year 1981 to under $600,000 in fiscal year 1982, and have eliminated WRSIC support for the Research in Progress File.

Material for SWRA is collected primarily by private centers of competence in particular water resource fields, supplemented by additional information from Federal agencies, State water resources research institutes, and a commercial abstracting service. The material is processed at the National Technical Information Service (NTIS), and made available in two forms: a journal, SWRA, published semimonthly, and computerized bibliographic retrieval services available through DOI and private sources. Approximately 15,000 new bibliographic entries are published and added to the system each year. The abstracts system currently holds over 150,000 full bibliographic references. WRSIC also uses the system to produce and publish an extensive topical bibliography series, and the OWRT research reports.

The *Water Resources Research in Progress File Catalog* is an annual compilation of about 2,500 summary descriptions of new or substantially revised research projects in water resources. Until October 1981, the file was compiled by the Smithsonian Scientific Information Exchange (SSIE) from material voluntarily registered there by Federal and other research organizations. NTIS has recently been given responsibility for compiling the Research in Progress File, and is developing procedures to streamline the compilation process. Since file entries refer to ongoing work, the file reports projects substantially in advance of SWRA, which can reflect only published findings. File information is accessible through computer retrieval systems at NTIS and through the private sector.

Both the Research in Progress File and SWRA contain information about models and modeling activities. However, since they are designed for much broader purposes, abstracts and research projects are referenced originally by subject areas —and are cross-referenced only under the general category, "model studies." It would be extremely difficult for these general bibliographic reference services to adequately address the specialized nature of modeling needs without making substantial changes in their capabilities—such as the ability to store and distribute computer programs.

National Technical Information Service

NTIS of the Department of Commerce serves as the primary source for the public sale of Government-sponsored research, development, engineering reports, machine-processable data and related software. It adds approximately 70,000 new reports annually to an information collection of over 1 million titles, of which over two-thirds are computer retrievable. NTIS publishes a number of user-information reports to keep users informed of available material, including a comprehensive biweekly journal summarizing new publications, 26 weekly abstract newsletters, with annual indices, and over 2,000 bibliographies. NTIS analysts are also available to match user requests to available material, using online computerized master files.

In addition, the statutory mission of NTIS includes the collection and sale of data files and computer programs from Federal sources. These are made available to users on magnetic tape, while documentation in the form of user and programing manuals is available in printed copy or on microfiche. Models must already be documented in order to be listed in NTIS files. Computer-based material is primarily indexed under the subject area(s) to which it refers—a retrieval system was developed specifically for locating computer tapes of models, but was poorly suited to this purpose. More recently, NTIS files of computer models have been combined with those of the General Services Administration (GSA) Federal Software Exchange Center (FSEC), as described below.

Following the elimination of SSIE, NTIS has recently been designated to compile the Research in Progress File, the water research portion of which was previously funded by WRSIC. As no funding was allocated to NTIS for compiling the file, the agency can only accept Notifications of Research in Progress for which submitting agencies have provided indexing and other preparatory work for computer retrieval.

Because water resource models constitute only a minute fraction of the entries in the NTIS system, proposals for increasing general NTIS capabilities to locate them and advise potential users about their functions are difficult to justify. As a general-purpose information center that is obligated by law to recover its costs from sales and distribution of product and services, NTIS cannot affort to serve as a modeling resource center. With regard to computer programs, it can be an effective mechanism for the distribution of an already-known model, but its functions are too broad to permit its effective use as a focus of modeling expertise and information.

GSA Federal Software Exchange Center

The Brooks Act of 1965 (Public Law 89-306) gives GSA authority to develop governmentwide guidance for automatic data-processing activities. Under this authority, GSA amended the Federal Property Regulations to create a Federal Software Exchange Program in February 1976. To implement the program, GSA created FSEC by interagency agreement with NTIS, using funding from the GSA automatic data-processing revolving fund.

The Federal Property Management Regulations require agencies to submit abstracts of computer programs considered usable by other agencies to FSEC at NTIS. The regulations specify that these computer programs must have been operational for at least 90 days, and require agencies to provide particular forms of documentation with the abstracts. FSEC currently compiles the submitted abstracts into the GSA *Software Exchange Catalog,* and sets prices for Federal, State, and local government agencies wishing to use the listed computer programs. Subscriptions to the catalog are provided for a $75 annual fee.

No mechanisms exist, however, for enforcing participation in the software exchange program. The determination of which programs are suitable for interagency use rests with each agency, and GSA has authority to do little more than persuade agencies to submit abstracts. Consequently, responses to the program have not met expectations —while GSA and NTIS officials planned for the receipt of up to 7,000 abstracts in fiscal year 1977, the first year of the center's operation, the inventory currently contains only about 1,300 abstracts, a small percentage of the software suitable for exchange.

For a program to be included in the *Software Exchange Catalog,* agencies must submit a tape of the actual program, documentation, and an information sheet specifying basic program characteristics. All software packages are routinely reviewed for completeness, but FSEC staffing levels do not generally permit the evaluation of submitted programs. Consequently, the FSEC inventory consists primarily of general submissions of unknown quality. Only a very small percentage of inventoried programs have been tested and enhanced by GSA, or are considered to be of special significance and known reliability. Moreover, to satisfy agency fears about receiving large numbers of direct inquiries regarding computer programs, software exchange program regulations further specify that the developer of submitted computer programs will not be identified to purchasers without the developer's prior consent.

Providing technical assistance to users has not been included as a major part of the FSEC mission—less than one staff-year of time was budgeted for this purpose for the first year of the center's operation. GSA's policy of recovering the costs of the program through sales of computer software appears to preclude higher levels of assistance. However, since potential users frequently have no access to developers under the program, many available models will remain unused for lack of the technical guidance required to adjust them to particular user needs. An early GAO report on FSEC activities (1978) summarizes:

> The GSA Software Exchange Program, as presently operated, is primarily a catalogue sales operation. In our opinion, many agencies will not buy software from this source because adequate technical assistance is not being provided.[19]

To enhance intra-agency software use, and expand the base for submissions to the FSEC inventory, FSEC has recently begun to offer technical assistance to Federal agencies on a reimbursable basis for establishing internal software inventories, and setting up coordination mechanisms for software development and use. FSEC is also negotiating with various specialized groups to catalog software in topical categories, geared to specific classes of users.

Existing Support Structures for Agency-Level Modeling Activities

The majority of Federal agencies that currently use water resource models lack comprehensive strategies for developing, using, and disseminating these tools. Modeling activities and expertise are dispersed throughout most of the agencies surveyed by OTA, with little apparent coordination, communication, or sharing of resources among individual modeling projects. However, two of the major users of water resource models—the Corps of Engineers and USGS—have developed programs that integrate all major phases of modeling activity, and function as a focal point for serving the modeling needs of nonagency users.

The two organizations employ widely divergent approaches for supporting model-related activities. The Hydrologic Engineering Center (HEC) of the Corps of Engineers is a discrete organizational unit that develops and supports *a limited number of carefully selected models* for use in a wide variety of applications. By contrast, *model development is dispersed* throughout the research activities of the Water Resources Division of USGS. A problem-solving focus is provided by the USGS Federal-State Cooperative Program, which assists State and local agencies in acquiring needed water resource information on a case-by-case basis, using analytical resources throughout the division to develop site-specific models that deal with the particular problem at hand. These two approaches are described in greater detail below to illustrate the major options available for agencywide coordination of modeling activities. In addition, a third organization—the Instream Flow Group of the U.S. Fish and Wildlife Service—is presented to illustrate the potential for advancing model use and modeling capabilities through innovative interdisciplinary, interagency analytical work.

Army Corps of Engineers' HEC

Established in 1964, HEC provides assistance in applying state-of-the-art technology (primarily mathematical models) to current hydrological planning, design, and operation problems. While HEC's initial purpose was to provide hydrological engineering services to the Corps of Engineers 52 offices, it currently supports the development and implementation of a broad range of water resource analysis and planning techniques. Services are provided extensively to non-Corps of Engineers users—private firms; other Federal, State, and local government organizations; universities; and foreign organizations—which currently account for over 80 percent of HEC model use.

HEC professionals locate, evaluate, and/or develop new procedures and techniques for analyzing water resources; develop and maintain 12 major computer models; teach currently available techniques and model use in formal training courses; and assist Corps of Engineers offices and others in applying models and techniques to current studies. To provide readily accessible user assistance, HEC assigns each of its major models to one or more engineers, who answer user questions over the telephone and handle unforeseen difficulties that may arise.

HEC has evolved a number of basic guidelines to ensure the widest possible use for the models it develops and/or maintains. Models are designed for general use, so that most problems in a field of interest can be solved with the same model, and

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[19] *The Federal Software Exchange Program—A Small Step In Improving Computer Program Sharing*, General Accounting Office, January 1978, p. 13.

Preliminary DRAFT
PLAN OF STUDY

Photo credit: © Ted Spiegel, 1982

Extensive field investigations, analyses, and public participation are part of the planning process for the Army Corps of Engineers' study of the Passaic River Basin. HEC provides analytical support for Corps studies, using a wide variety of modeling and other planning techniques

require little or no program modifications. Commonly accepted techniques are used where possible, and a variety of approaches is provided within an overall modeling package to suit individual needs and preferences. All programs are written in a commonly accepted computer language (FORTRAN IV), and are also designed to be easily transportable to a wide variety of computer types.

The ease with which the model can be used is also an important design criterion. To document models, HEC develops both user's and programer's manuals. The user's manual is written both to allow the beginner to use the model easily and to permit experienced users to employ the model for complex problems. The procedures for entering data into the computer are designed for simplicity, and are thoroughly described in the user's manual.

HEC distributes copies of its models and documentation without charge to a variety of users; private firms are charged a nominal fee for reproduction and handling costs. A November 1976 survey showed an annual distribution of approximately 700 model copies, and found that over 2,700 copies of HEC models were still in use by the offices that received them. HEC also publishes newsletters, professional papers, computer program abstracts, and training course notebooks to promote the use of its models.

Training courses are an integral part of the HEC user assistance program. The center provides 24 weeks of training courses annually for Corps of Engineers staff, reserving approximately 10 percent of the space in these courses for non-Corps of Engineers personnel. A number of the HEC-developed courses have also been adopted for use by U.S. and Canadian universities. Fifteen of the HEC courses have been videotaped; tapes and instructional material are available for loan, and may be used by visitors to HEC in conjunction with individualized instruction from center staff. Despite these efforts, however, HEC staff acknowledge that insufficient training is currently available to the non-Corps of Engineers user.

USGS Water Resources Division

USGS is a service-providing organization charged with collecting data on and analyzing the Nation's physical resources. Its Water Resources Division collects long-term multipurpose data on surface water, ground water, water quality, and water use; performs special interpretive studies of the physical, chemical, and biological characteristics of water; and conducts appraisals for environmental impact evaluation, energy development, coastal zone management, subsurface waste storage, waste utilization, land-use planning, flood plain management, and flood warning systems. Water resource models are used in all phases of the division's activities, and are an integral part of its analytical capabilities.

The division undertakes a substantial amount of data gathering, resource investigation, and research for general use throughout the Federal Government. It also carries out work to meet the analytical needs of other Federal agencies on a cost-reimbursable basis, involving funding tranfers of nearly $30 million in fiscal year 1978. Nearly half the division's budget, however—$70 million for fiscal year 1978 —was involved in activities carried out for the Federal-State Cooperative Program. The program, funded on a 50-50 basis by the division and State and local governments, provides data, information, and analyses to over 600 non-Federal agencies, concentrating on problems whose solutions are of mutual benefit to Federal, State, and local water resource professionals and decisionmakers. More requests for studies and offers of matching funds are received by the division each year than can be undertaken under current funding levels; decisions and negotiations regarding projects are made on a decentralized basis through 47 district offices. Most arrangements for undertaking studies are formalized with a simple one-page standard cooperative agreement.

Research and analytical work for the cooperative program is implemented under USGS direction, principally by Water Resources Division staff. These activities take place primarily at the division's regional centers in Reston, Va., Lakewood, Colo., and Menlo Park, Calif.; at the Gulf Coast Hydroscience Center at Bay St. Louis, Miss.; and occasionally in other sections of the country as needed. The combination of decentralized planning and coordinated interdisciplinary analysis at central locations allows the program both to be responsive to real-world problems and indications of emerging priorities, and to pool manpower and expertise in the relatively small field of hydrology.

When a model is needed to perform a particular analysis, USGS professionals develop one to suit the specific site characteristics under study. Thus, each model developed by the division is an individually tailored, single-use model, though it may often be based in part on a previously developed research prototype or an earlier modeling effort. Models and model-related activity account for between 10 and 12 percent of the Water Resources Division operating budget—from $12 million to $15 million was spent on applying models to specific problems, and from $3 million to $4 million on research, in fiscal year 1979.

Tracing Ground-water Movement
By Using the Stable Isotopes
Of Oxygen and Hydrogen, Upper
Penitencia Creek Alluvial Fan,
Santa Clara Valley, California

Photo credit: © Ted Spiegel, 1982

USGS investigations of water problems are often coupled with laboratory research and modeling activities to provide the information necessary for a thorough analysis. Here, a USGS research scientist demonstrates computer-controlled lab equipment used to make calculations for the study shown in foreground

One of the keys to the strength of the USGS effort is the reputation for impartiality enjoyed by the division's studies. Many of the projects it undertakes are associated with controversies among conflicting interests. Because the division's analyses are perceived to be relatively free from mission-oriented biases, its results tend to be accepted by all parties to interstate, intrastate, State-local, and international disputes.

USGS also provides extensive hydrological and water resource-related training. Courses are conducted primarily at the USGS National Training Center at Lakewood, Colo., and include a large number of sessions on modeling surface water, ground water, and water quality. Open to personnel throughout the Federal Government and from State agencies and international organizations, courses are geared toward various levels of professional expertise, some of them designed for administrators, others for technicians and resource specialists. Nationally and often internationally recognized scientists and engineers from the Water Resources Division serve as the main instructional staff for training sessions. Experts from other divisions of USGS, other Government agencies, universities, and private industry also serve as lecturers and special consultants.

Cooperative Instream Flow Service Group

The extensive development of water resources in the Western United States over the past 15 years has had major effects on the availability of water for instream uses such as recreation, and fish and wildlife needs. During this period, concern over rapid decreases in instream water availability created broad-based expressions of need for a comprehensive source of information and expertise on standard tools for analyzing instream water needs. Such concern reached major proportions by the mid-1970's— particularly in the Pacific Northwest, where protection of the anadromous fish resource has been an acute problem for many years.

During the early 1970's, a number of entities engaged in analyzing instream flow problems both from a technical and legal/institutional perspective. The general response of natural resource management agencies, and the U.S. Fish and Wildlife Service in particular, was to organize groups of fisheries or wildlife biologists to make suggestions to the water management community. This approach proved relatively unsuccessful, as resource managers were not inclined to give strong credence to a solely "biological" perspective. As an alternative, the Office of Biological Services within the Fish and Wildlife Service proposed to develop an interdisciplinary, service-oriented center for instream flow analysis, drawing personnel from numerous Federal and State Government agencies. Funding to create this center—the Cooperative Instream Flow Service Group—was eventually provided through EPA for fiscal years 1976 through 1979. Funding is currently provided directly by DOI.

Potential users of Instream Flow Group (IFG) services identified two major needs: 1) information on biological and hydrological aspects of instream uses; and 2) information on institutional means currently (or potentially) available for ensuring adequate stream flows. Satisfying these needs required the creation of a team of personnel encompassing the biological, physical, and social sciences to gather, collate, and disseminate information on instream uses. Model developers and users were also considered a necessary part of the team effort, in order to create usable mathematical tools for instream analysis. Staffing for IFG was accomplished through the Fish and Wildlife Service, State agency personnel recruited under the Intergovernmental Personnel Act, and detailees from other Federal agencies.

Since its inception, the group has concentrated on transferring information on instream uses via computerized data retrieval systems, library functions, preparing information papers, training, and providing technical assistance on various aspects of stream flow protection. Two of its major analytical efforts have been in developing methods to: 1) analyze the effects of incremental changes in flow on instream uses such as fish and wildlife habitat; and 2) analyze tradeoffs between instream and offstream uses as part of regional water assessments.

In the first area, IFG has developed the instream flow incremental methodology, an analytic approach to evaluating changes in the fish-carrying capacity of stream reaches. This methodology has been widely adopted for use in Western and Midwestern States. For the second area, work is in progress for a regional reconnaissance method to evaluate general stream characteristics within a water basin. Using the Upper Colorado River Basin as a case example, the group is attempting to develop a unified basin modeling approach as a decisionmaking tool to determine the cumulative effects of various water management schemes.

The group provides two types of assistance to improve the level of competency among users of its computer-based models. First, it offers an array of *training opportunities* designed to inform participants about the basic issues, develop an overview understanding of solutions to the problem, and finally, provide instruction in using computer-based models. The group maintains an extensive training program throughout the Western United States on such subjects as western water law, strategies for protecting instream flows, and negotiating instream flows. In addition, the group offers training in the use of modeling technologies. For example, its instream flow field techniques short course and its computer analysis short course are designed to give the user the technical competence required to conduct analyses of instream flow requirements.

Second, IFG provides *technical assistance.* This entails helping users who are engaged in instream flow analysis to develop study plans, make measurements, analyze data, develop and present recommendations, and implement them. Technical assistance also involves assisting State and Federal water administrators in determining areas and opportunities for factoring instream uses into State water plans or land management plans.

IFG officials attribute the group's success to its strong interdisciplinary focus, the quality of its personnel, clear identification of the problems to be addressed, and frequent interaction among staff members and group leaders. The communication engendered among professionals in a number of disciplines is considered a vital prerequisite to devising methodologies, solutions, and recommendations credible to the wide range of interests that are party to water resource management decisions.

Agency-Level Mechanisms for Providing Information on and Access to Existing Models

A number of mechanisms are currently used in various Federal agencies for making model-related information available to users. Such services may range from simple directories of available models; to user support groups for transferring modeling technologies; to clearinghouses that match user needs to available models, test and evaluate modeling systems, and provide user training. Four major agency efforts are described below: 1) the International Clearinghouse for Groundwater Models (ICGWM); 2) the EPA Stormwater Management Model (SWMM) User's Group; 3) the EPA Center for Water Quality Modeling; and 4) the USDA Land and Water Resources and Economic Modeling System (LAWREMS). Each represents a substantially different approach to managing model-related information and improving user access to existing modeling systems, and addresses different kinds of user needs.

International Clearinghouse for Groundwater Models

Studies begun in 1975 at the Holcomb Research Institute indicated that, while significant progress had been made in developing and using numerical models for ground water-related resource management, major gaps existed between the need for and the existence and actual application of ground water models. Access to existing models, and identifying models designed for specific applications, were observed to be serious problems. The gulf between model developers and model users needed to be closed by developing mechanisms for transferring modeling technology from experienced modelers to others needing these important analytical tools.

Further research work, funded by EPA and the Scientific Committee on Problems of the Environment, developed guidelines for establishing a clearinghouse to assist users of ground water models, and an outline of the primary objectives and services of such a center. ICGWM became operational when EPA funded a 3-year project to staff and fulfill the clearinghouse objectives at the Holcomb Research Institute. The project is intended to test the utility of the clearinghouse approach to technology transfer using ground water models as an example.

The clearinghouse concept is based on the idea that a central information source can greatly reduce the effort normally required to acquire model information. Through the clearinghouse, the potential user can be exposed to all levels of available technologies and can expeditiously determine which is most appropriate for his purposes. Further, a clearinghouse provides a natural setting for testing and evaluating models, and for education in model applications, operations, and theory for nontechnical and technically trained personnel alike.

The first major activity of ICGWM was to develop a ground water model information search and retrieval system. A model annotation form—a detailed checklist containing both general and specific model characteristics—was circulated international-

best copy available

ly to known model developers, with a request to complete the form by checking off those characteristics that apply to their models. These forms were used to develop a computer-assisted Model Annotation Retrieval System (MARS). As of February 1982, MARS had over 400 unique model annotations—and their number is constantly growing.

To access information, the same model annotation form is distributed to interested model users. The user checks off the desired model characteristics and returns the form to the clearinghouse, where MARS compares it to the stored models and identifies those that meet all or most of the desired characteristics. This retrieval system is designed to avoid the complexities that plague traditional systems controlled by key words. Its success can be gaged by the fact that user requests for model information grew from an average of 6 per week during the first 6 months of operation to 85 per week as of April 1980.

Moreover, developers have begun to recognize the commercial value of having their models included in MARS. Evidence of competition has recently been observed among developers to ensure that their works are available to potential users through the clearinghouse.

The second phase of development at the clearinghouse involves the acquisition, evaluation, and recommendation of available models. ICGWM is currently assembling a selection of functional models that: 1) are available; 2) have been tailored to current key ground water problems; and 3) have been tested for accuracy, usability, and transferability. A screening process is being developed to examine models for validation and performance, and to create documentation guidelines for model software. In the process, close attention will be given to the model user's manual compiled by the model developer.

The other major activity started during the second phase of development is a series of workshops on ground water modeling. The workshops, held annually at the Holcomb Research Institute, are structured in a stepwise fashion, beginning with a general introduction to the applications and limitations of models for policymakers and decisionmakers, and progressing toward advanced mathematical theory in later workshops. The last three sessions are "hands-on" experiences where the attendees vigorously work with computer models and developers. The first series of workshops was conducted with an enrollment of 140; indications are that the workshops have been highly successful in educating water resources professionals about the potential of models. Future plans call for presenting the general session at regular time intervals at regional centers throughout the United States, and the entire workshop series at various international locations.

The third phase of development calls for establishing formal international linkages to the center, and developing financial support to continue the expansion of the clearinghouse. To the latter end, ICGWM plans to undertake technology transfer activities to assist users, operating under an established fee structure for technical consulting work. However, charges for these services, the workshops, and the use of MARS are unlikely to cover the cost of daily operations—outside sources of funding will need to be secured to support clearinghouse activities. ICGWM officials suggest that an appraisal of the cost effectiveness of the center will only be possible once all of its major activities are fully operational. Over time, however, as demands for services grow, the clearinghouse is likely to require less financial assistance from outside sources.

ICGWM officials consider that the clearinghouse has been successful thus far in making ground water modeling information accessible, in reducing the time and effort required for model users to acquire appropriate modeling tools, and in educating interested professionals about the benefits and limitations of models. The clearinghouse approach also appears to hold major potential as an effective medium through which new technologies can be transferred.

SWMM User's Group

EPA's SWMM is one of the largest and most comprehensive mathematical models for simulating storm and combined sewer systems, their associated storage and treatment facilities, and their impacts on receiving waters. Its reliability and widespread availability have made SWMM the most widely used model of its type in the United States and Canada, and have been important in increasing the use of models by engineers and planners. The SWMM User's Group has been instrumental in achieving the widespread dissemination and acceptance enjoyed by this important modeling tool.

Initially developed in the early 1970's, SWMM is a complex, computer-based model that simulates the movement of stormwater through a watershed, determines quantity and quality of runoff, routes this runoff through a combined (or separate) sewer system with specified storage and treatment facilities and operating policies, and thence into receiving waters, where resulting water quality is quantified. SWMM is modular, having five computational blocks—each of which can be used alone or with other blocks.

When the model first became operational, EPA's Office of Research and Development (ORD), which sponsored the development of SWMM, decided to organize an informal user's group as its principal means of technology transfer. ORD recognized that the model's principal users would not be EPA staff, but rather the members of the consulting engineering profession, acting on behalf of EPA, or of State, regional, or local governments, or industrial and commercial clients. These model "clients," who are normally free to select the models to be used, generally base their decision on a model's ease of use, cost effectiveness, and reliability.

To assure that SWMM would be readily usable, ORD devoted substantial attention and resources

Photo credit: © Ted Spiegel, 1982

Modern urban development has substantially increased both the complexity of urban runoff management and the need for adequate sewer transport, storage, and treatment of runoff. The Albany, N.Y., skyline provides a dramatic demonstration of the interactions between built-up urban areas and natural water bodies. Models such as EPA's SWMM can be used to assess the impact of Albany's runoff on flows and water quality levels in the Hudson River to documenting and testing the model before attempting to disseminate it. All or parts of SWMM were tested in five different locations, and the results of the tests included in the original documentation. This, in the judgment of the SWMM developers, was the single most important factor in gaining acceptance for the model.

The first step in creating a technology transfer program for SWMM was to set up a mechanism for distributing the model and its documentation. Working from a small list of interested people, ORD offered to duplicate the model and documentation for anyone who sent in a blank tape. Since 1972, over 300 users have received copies of the program, and perhaps 1,000 copies of the documentation have been sent out. Test data are furnished with the program to allow each recipient to check that the model is operating correctly.

User's Group meetings were seen as the best mechanism for transferring knowledge among experienced model users and those who were new to SWMM. The meeting approach combines instantaneous communication of current knowledge with close interpersonal association and support for model users.

About 20 individuals attended the first SWMM User's Group meeting in early 1973. Since that time, meetings have been held on a semiannual basis, and the group membership has grown to almost 500, including representatives from 19 foreign countries. An informal user's bulletin, first published in 1973, has been sent out periodically, to announce meetings or other items of interest.

User's Group meetings are colloquial and informal in atmosphere, in order to allow a high degree of interaction between individuals with common interests and problems. To encourage group members to examine other models that may be made applicable to their problems, at least one presentation per meeting focuses on the use of a different water quality model. Since 1977, formal User's Group proceedings have been published to record meeting activities.

To maintain and update SWMM, ORD decided on the services of an outside contractor, rather than attempting to use in-house resources. The decision was based in part on the perception that in-house efforts tend to become self-perpetuating and to stifle creative change. In addition, the group that maintains the model is available to users for over-the-telephone questioning or detailed consulting on a normal fee basis. This supplements the informal free advising network among users, and the availability of User's Group members to consult on a fee basis when needed. EPA has resisted requests to make minor changes in the program. Three updated versions of the model have appeared since the original; users are encouraged to make other local changes that they desire.

Initially, training in the use of the model was sponsored by EPA; since 1976, however, the only available formal training has been offered privately by various universities. The agency's experience has been that, given the support of the User's Group, model users are generally willing to train themselves. In this sense, the User's Group has evolved into an inexpensive alternative to agency-sponsored training programs.

Costs associated with the SWMM User's Group have been relatively low. The group requires about 20 percent of the time of one professional, about 10 percent of one secretary's time, and about $5,000 per year to cover printing costs for meeting proceedings. Other costs include mailing, newsletter printing, maintaining the User's Group list on a time-sharing computer, and duplicating the SWMM program—all of which consume perhaps $2,000 to $3,000 per year at most. Meeting costs are minimal—since no travel expenses or honoraria are paid to speakers—and are covered entirely by registration fees.

EPA Center for Water Quality Modeling

ORD established the Center for Water Quality Modeling in 1980 to distribute, maintain, and provide technical assistance in the use of selected EPA-developed water quality models. The center, located at the Environmental Research Laboratory in Athens, Ga., serves as a focal point for assisting users in locating and applying models developed by EPA operating and research programs.

EPA's use of water quality models increased rapidly in the 1970's. Separate model development activities within individual EPA offices resulted in a proliferation of seemingly different models, although many models were actually modifications and/or extensions of earlier modeling attempts. The lack of a central reference point for model use within the agency impeded the correction of initial modeling errors, so that errors tended to be propagated in successive modeling activities. Additional impetus for creating an office to support and maintain frequently used models came from the growing need to provide expert technical/analytical assistance to States and EPA regional offices. The success of EPA's own SWMM User's Group and the Corps of Engineers' HEC in encouraging widespread model use and acceptance pointed to the large potential benefits to be derived from such an office.

The center's initial support role has been limited to four widely used modeling packages: 1) QUAL-II (a stream water quality model); 2) SWMM/RECEIV (an urban runoff model); 3) ARM (an agricultural runoff management model) and NPS (a general nonpoint source runoff model); and 4) HSPF (a multipurpose hydrologic simulation program). Center staff provide copies of model documentation and tapes of the models' computer codes to interested users, and relay information about errors or other problems back to the models' developers. Center personnel are currently evaluating a number of models for possible addition to the four packages presently being supported, and are developing a quantitative model selection procedure to assist users.

A number of older EPA models are also on file at the center; however, current manpower limitations do not permit them to be supported or maintained. Computer programs, manuals, reports, etc., for these models are distributed on request on a "use at your own risk" basis. While the center routinely receives requests for models in this category, it has not checked, corrected or updated them, and functions primarily as an archive in this area.

For its supported model packages, the center assists users by sponsoring intensive "hands-on" workshops and technical seminars, taught by experts from the Environmental Research Laboratory and representatives of the organizations that developed the model under EPA grants or contracts. Workshops are open to all model users, and the level of user interest dictates the number of workshops presented. For fiscal year 1980, several workshops were held on the HSPF; two sessions were held on QUAL-II. A newsletter for informing users of training opportunities, advising them of modeling errors or updates, and quickly providing additional model-related information was introduced in September 1980. Superseding and expanding on the SWMM User's Group Newsletter, the new publication has used the audience established by its predecessor as a base for informing users of the center's existence and activities. Current administration policy, however, prohibits the center from publishing the newsletter.

At present, the center's manpower resources are very limited; consequently, it does not offer routine "online" technical assistance to all model users. While limited technical assistance is available on specific agency problems, and can be provided through procedures established prior to the center's inception, even such requests are generally discouraged. To expand the availability of technical assistance in running models, the center concentrates on developing user interaction activities, based on the user group concept, in order to teach users to solve their own problems. Such an approach has in the past proved highly successful in encouraging the use of standardized, widely applicable models. However, inclusion of additional, more specialized models in the center's support role would likely call for the provision of greater levels of technical assistance by center staff.

USDA Land and Water Resources and Economic Modeling System (LAWREMS)

A December 1976 request from the Senate Committee on Agriculture, Nutrition, and Forestry for USDA assistance in evaluating the department's land and water conservation programs provided the initial impetus for the creation of LAWREMS. As a followup to its report to the Senate, the USDA Land and Water Conservation Task Force created a modeling team composed of representatives from major USDA agencies, giving it the responsibility to develop an information system about current data and analytical capabilities within the department, and to outline future goals and directions for integrated departmentwide modeling systems.

The LAWREMS team developed a computerized directory of data sets and models related to water and land resource analysis, relying primarily on those created by various USDA agencies. The team also established a file of related documentation and reports, arranged for ongoing computer assistance to facilitate access to and transfer of data and models, and created a small staff to maintain the directory and provide limited technical assistance to users.

The initial LAWREMS directory contained approximately 300 descriptions of models and data sets, each of which included such information as title, agency, an abstract, purpose, keywords, geographic coverage, operational status, name and address of technical contact, and basic technical information. The directory is currently housed within the Resource Systems Program of the Economic Research Service.

While LAWREMS support services include direct access to a limited number of models and data sets within USDA, its primary function is to direct users to the individuals or organizations that have developed these tools. The system is intended to improve communication among program analysts and researchers about existing data and models, their use, limitations, and linkages. The existence of such a system is also intended to encourage the upkeep, maintenance, and use of existing data files and models. Services are provided primarily to USDA analysts working in the area of resource conservation; however, expanding access to include other USDA personnel, as well as interagency and non-Federal use, has been envisioned as part of future LAWREMS activities.

LAWREMS support staff are responsible for maintaining and updating the directory, and provide some technical assistance to USDA land and water conservation program evaluators and analysts. Provision of "hands-on" training to a limited category of users on selected data and analytic systems is contemplated as part of ongoing staff activities. Staff would also provide assistance in coordinating agency efforts to design new models or modify existing ones, along with identifying data requirements, when information is not available or accessible from existing sources.

Chapter 5
Use of Models by State Governments

Summary of Model Use by Individual Water Resource Issues
Surface Water Flow and Supply Issues
Surface Water Quality Issues
Ground Water Issues
Economic and Social Issues

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Chapter 5

Use of Models by State Governments

State governments have extensive water management responsibilities, ranging from flood control to prevention of ground water contamination to comprehensive river basin management. These responsibilities have increased in recent years, due in part to Federal environmental legislation that relies on Federal-State partnerships to address a wide variety of national water resource problems. The Clean Water Act, the Resource Conservation and Recovery Act, the Water Resources Planning Act of 1965, and the Safe Drinking Water Act, in particular, assign States numerous additional obligations requiring high levels of technical expertise and highly sophisticated planning and management decisions.

Computer models can significantly aid States in undertaking these added responsibilities. While several States have sophisticated modeling capabilities, many State officials acknowledge that the use and understanding of models by State agencies is far below the level it should be. To gain a better understanding of factors affecting model use at the State level, OTA surveyed professional-level personnel at water resource agencies in all 50 States. This chapter reports the results of that survey, including the kinds of models used, the extent of their use, and the problems encountered by State water resource professionals. It contains:

- summary of survey results;
- procedure used for conducting the OTA State modeling survey;
- trends in current and potential State model use;
- major constraints to model use identified by State personnel; and
- State model use in individual water resource issue areas.

SUMMARY OF SURVEY RESULTS

State water resource professionals generally use computer models developed by others—particularly Federal agencies. The size, budget, and technical capabilities of most State water resource agencies do not permit them to develop models; consequently, State model use depends on having access to federally developed models and on the availability of federally sponsored training and technical assistance.

In many States, model use is primarily restricted to a few well-established, widely available models. State personnel are often poorly informed about the availability of models and data, and about technical assistance available to facilitate model use.

Data inadequacy was the most frequently cited constraint to effective State model use. While most State officials indicated that increased Federal funding for data collection would improve State modeling efforts, they also emphasized the importance of improving access to Federal (and other State) data bases.

Low salary levels and high turnover rates were also stressed as hindrances to States' efforts to maintain staffs with expertise in modeling. After data needs, States placed highest priority on increased federally sponsored training in model use and applications for both technical and managerial personnel. Other major State concerns included the need for Federal sponsorship of simpler models for State-level use, and improving the reliability and credibility of models through Federal coordination, clearinghouse activities, and standard-setting.

PROCEDURE USED IN CONDUCTING THE OTA STATE MODELING SURVEY

OTA surveyed State agencies responsible for the supply and quality of freshwater resources in June 1980 to determine the extent of their current and potential water resource model use. State personnel were asked to identify major problems facing the States in using models and Federal policy options to improve State model use.

The survey was divided into two major sections. The first assessed existing and potential State model use in four major water resource areas: 1) surface water flow and supply; 2) surface water quality; 3) ground water; and 4) economic and social concerns. These areas were further divided into a total of 33 water resource issues.* Model use for each of these issues was assessed for three different decisionmaking functions: 1) operations and management; 2) planning and policy; and 3) other (primarily research). The respondents were also encouraged to provide additional information on the role of models for each of the 33 water resource issues—e.g., the specific regulations for which the model is applied. Detailed results of this portion of the survey are compiled in appendix E.

The second section of the survey posed three broad questions on State model use:

1. Identify the most important needs associated with water resource model development in your State, and suggest options available to the Federal Government to assist your State.
2. Identify the most important problems and needs associated with water resource model maintenance in your State, and suggest options available to the Federal Government to assist your State.
3. Summarize reasons models are or are not used by your State. Consider the reliability and credibility of models, and human/institutional problems. Suggest options available to the Federal Government to assist your State in model use.

Surveys were sent to State agencies responsible for both water quality and water supply concerns in each State. Since these responsibilities often rest with different State agencies, surveys were sent to different agency contacts for water supply and water quality issues. Names of key agency contacts were suggested by the State water resources research institutes.

Six surveys were sent to each State agency contact (two contacts from each State)—a total of 612 surveys. Each contact was asked to circulate these surveys among the agency personnel familiar with the use of models in the State for the 33 listed water resource issues. Most of the surveys returned were submitted independently by individual agency personnel; some of the States, however, returned a single response that had been circulated throughout the agency.

All 50 States and the District of Columbia returned completed surveys. However, the number of surveys returned from each State varied from one to six. A total of 103 surveys were returned.

TRENDS IN CURRENT AND POTENTIAL STATE MODEL USE

Forty-eight States currently use water resource models. Collectively, the States employ these models to address problems for all 33 identified water resource issues. However, it is clear that most States use only a few of the many models available—primarily those based on well-established modeling techniques like wasteload allocation or ground water supply models.

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*A discussion of the modeling techniques used to analyze each of the four major resource areas, and a review of the problems and modeling capabilities associated with each of the 33 water resource issues, is presented in ch.6.

The majority of States use models for less than 10 resource issues, and 14 States (28 percent) use them for five or fewer resource issues. Only one-fifth of the States use models for more than 15 issues (see table 5 and fig. 7).

In contrast to their current model use, a majority of the States identified potential uses for models in more than 20 of the 33 water resource issues. Nearly one-fourth of the States indicated that they could use models for over 30 issues. These statistics indicate that although models are currently used for a limited range of issues, State officials see increased model use as important for expanding State roles in water resources management, planning, and policy (see fig. 7).

Large discrepancies between existing and potential model use can be highlighted by ranking each of the 33 resource issues according to the percentage of States indicating current or potential model use.* Table 6 lists the States' top 10 existing and potential water resource modeling uses, and figures 8-11 illustrate the percentages of States indicating current and potential use of models for each of the 33 water resource issues.

These data indicate several trends: surface water flow models are currently the most widely used—5 of the 10 top-ranked resource issues are surface water flow issues. For ground water issues as well, supply and flow models rather than quality models receive the greatest amounts of current use. Three of the top 10 issues, however, are surface water quality issues. One of them, wasteload allocation, is the issue for which the greatest number of States indicated current or potential model use. While most States do not often employ models to assess water quality problems, the few problems that have been studied most—e.g., wasteload allocation and erosion/sedimentation—are widely analyzed using models. States tend to be frequent users of flow and supply models, in part because Federal agencies have been active in developing and applying them. The Corps of Engineers and the U.S. Geological Survey (USGS) actively assist States in modeling efforts for flood forecasting and control, drought and low-flow forecasting, streamflow regulation, domestic water supply, ground water supplies and

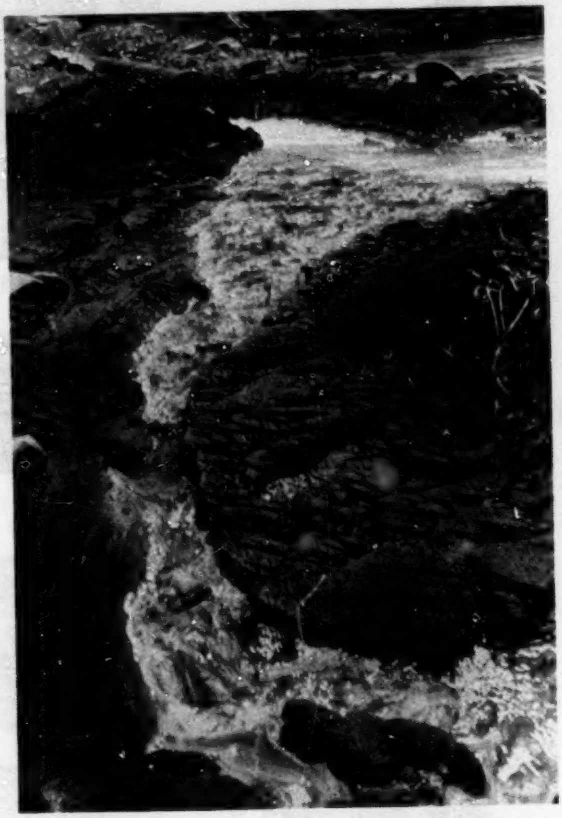

Photo credit: Environmental Protection Agency

Water quality concerns, and the models used to analyze them, are increasingly important to State agencies. While only 3 of the States' 10 most important model use areas are currently water quality issues, OTA's survey of State officials shows that 7 of the 10 top water modeling areas are expected to involve water quality in the future

Table 5.—Number of States Indicating Existing or Potential Model Use

Number of issues	Existing	Potential
0 through 5	14	2
6 through 10	14	8
11 through 15	12	4
16 through 20	5	7
21 through 25	3	9
26 through 30	2	8
31 through 33	0	12

SOURCE: Office of Technology Assessment.

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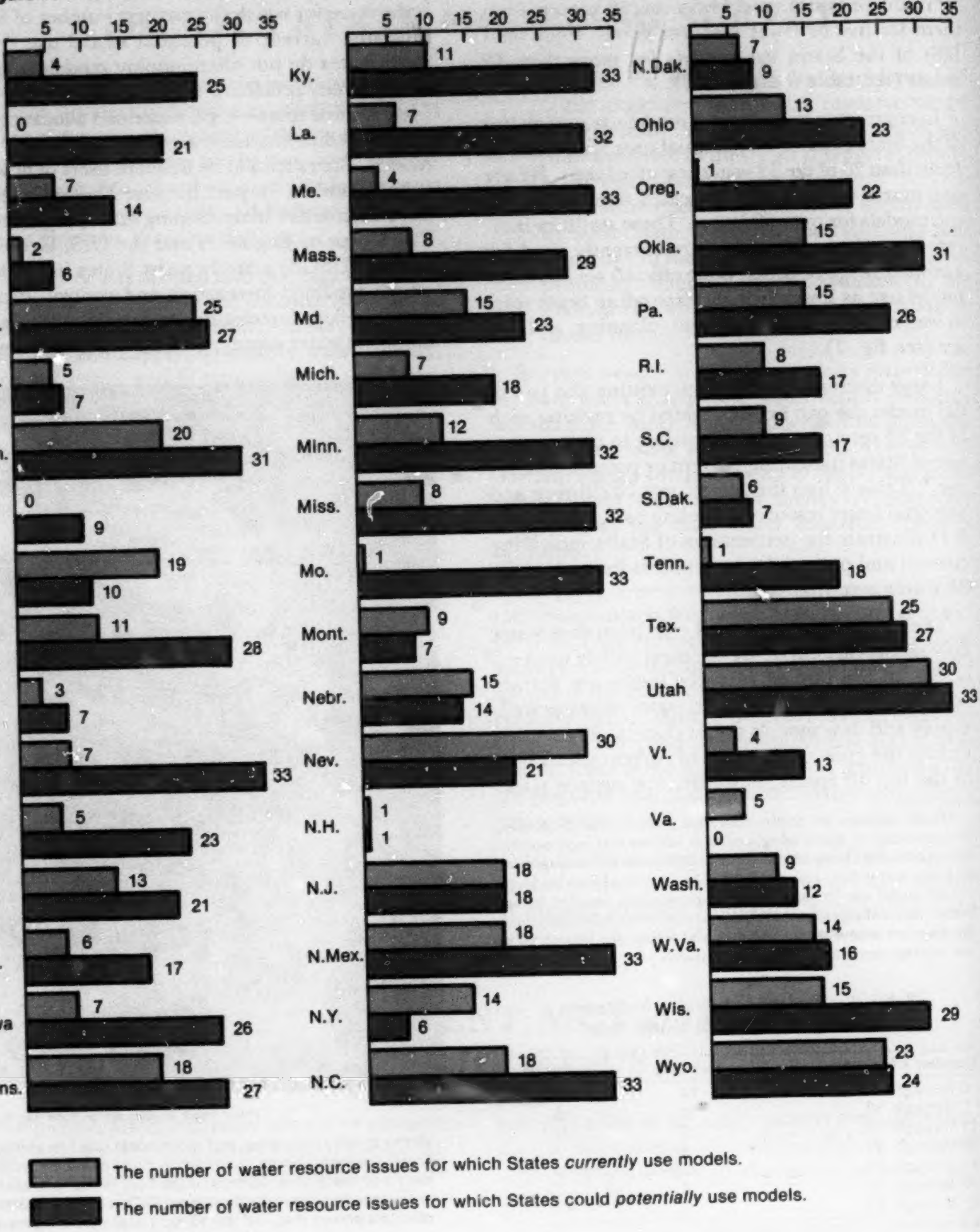
*These rankings are obtained for each resource issue by totaling the percentage of States using models to address that issue over the three specified decisionmaking functions (operations and management, planning and policy, and research). This combined number better reflects model use for each issue than percentages reported for any one decisionmaking category. A State may use several different models for the same issue—one for planning and policy, one for operations and management, and another for research.

Figure 7.—Number of Water Resource Issues for Which States Indicated Current or Potential Model Use



SOURCE: Office of Technology Assessment.

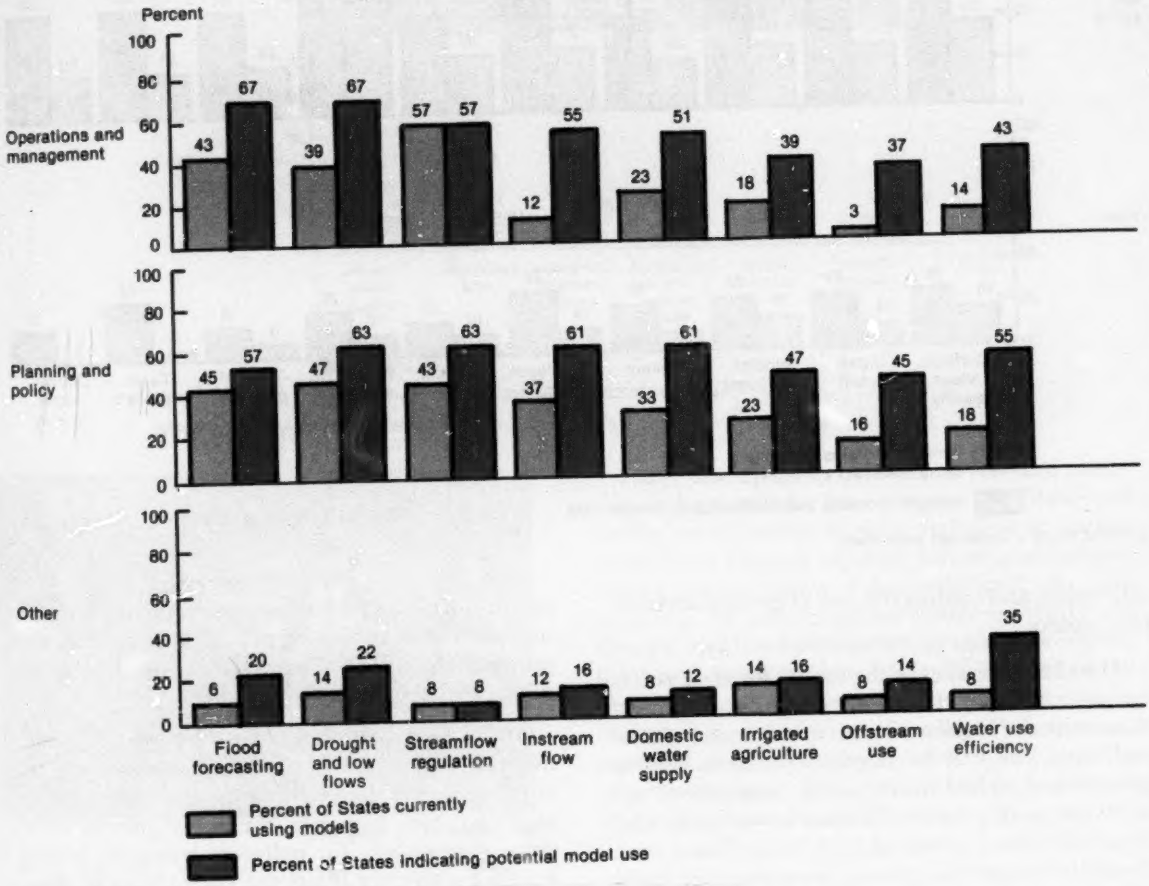
Table 6.—Rankings of State Model Use for All Water Resource Issues (top ten)

Existing	Potential
Wasteload allocation	Wasteload allocation
Ground water supplies and safe yields	Conjunctive use
Streamflow regulation	Drought and low-flow forecasting
Drought and low-flow forecasting	Impacts on aquatic life
Flood forecasting and control	[a] Ground water supplies
Conjunctive use	Waste disposal—ground water
Impacts on aquatic life	Agricultural pollution—ground water
Erosion/sedimentation	Urban runoff
Domestic water supply	Erosion/sedimentation
Instream flow	Accidental contamination of ground water

[a] Tied for fifth place

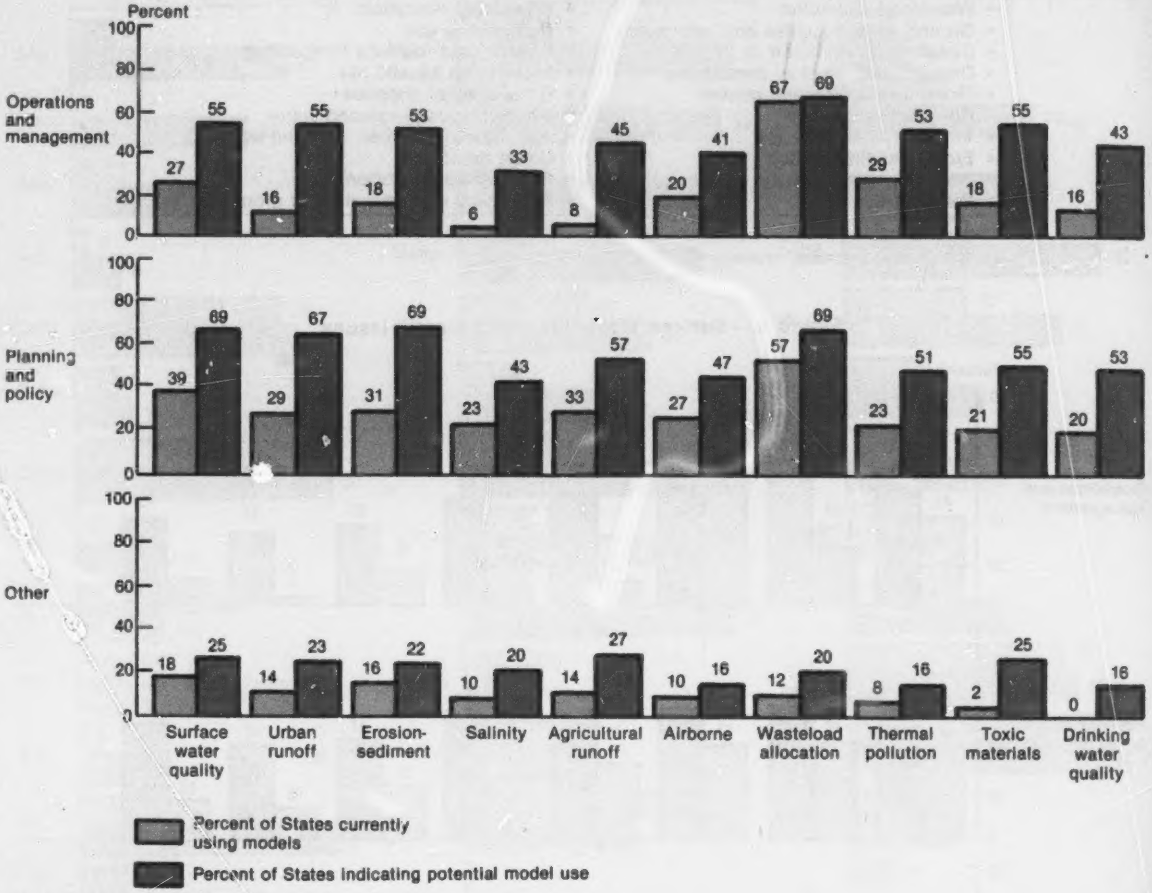
SOURCE: Office of Technology Assessment.

Figure 8.—Surface Water Flow and Supply Issues



SOURCE: Office of Technology Assessment.

Figure 9.—Surface Water Quality Issues



SOURCE: Office of Technology Assessment.

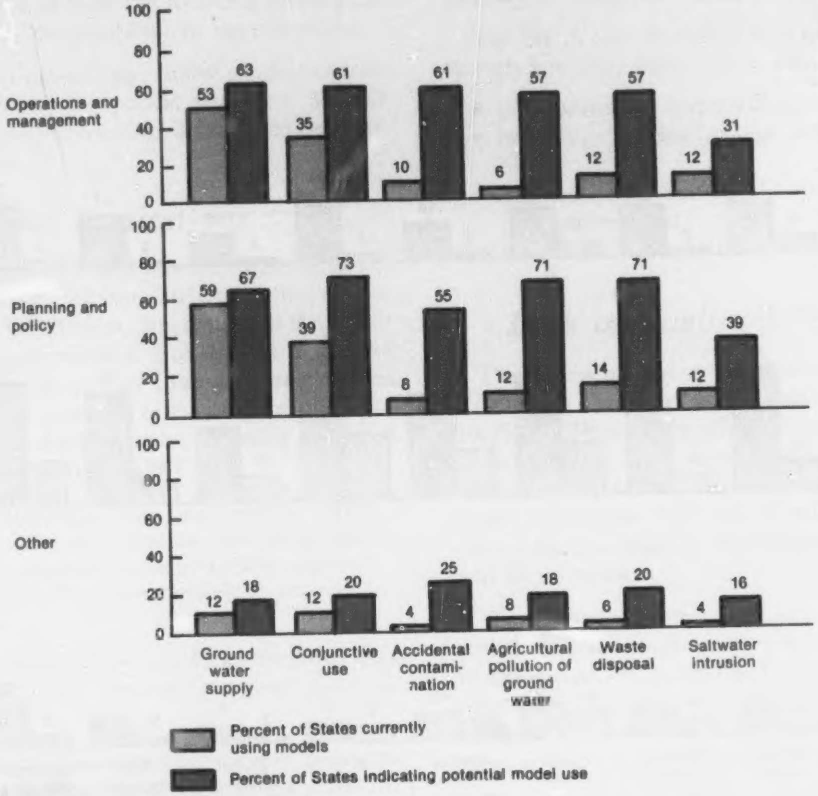
safe yields, and conjunctive use of ground and surface waters.

The characteristics of the top 10 resource issues for potential model use differ significantly from those with the highest current use. Instead of flow and supply, most of the identified problems involve ground and surface water quality concerns—7 out of 10 are quality issues. Ground water issues also stand out among potential model uses; States rank five of the six specified ground water resource issues in the top 10.

One reason for the widespread potential reported for surface water quality models is the extensive responsibilities that States have acquired for meeting national clean water goals. Models have an important role in States' compliance with numerous sections of the Clean Water Act.

Many States stress the need for ground water models because modeling techniques are often the only method of determining the characteristics of major aquifers. However, the lack of ground water data—particularly for pollutant transport within aquifers—severely limits the current use of these models. In general, deficiencies in data and lack of knowledge of physical processes are more serious constraints to the use of ground and surface water quality models than for flow and quantity models.

Figure 10.—Ground Water Issues



SOURCE: Office of Technology Assessment.

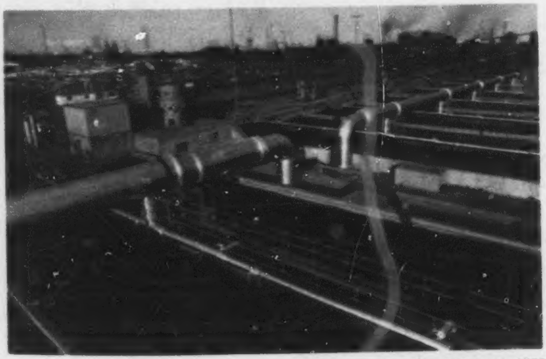
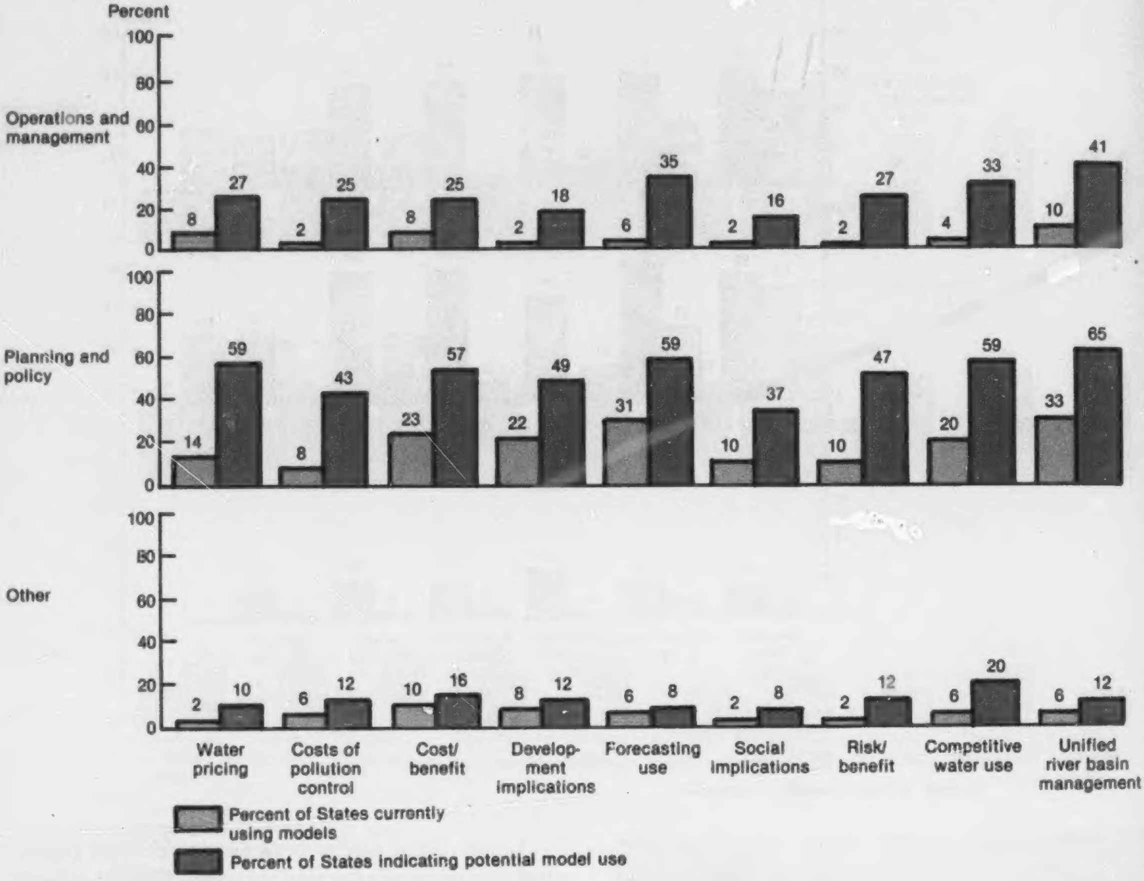


Photo credit: © Ted Spiegel, 1982

State and local water quality agencies have major responsibility for designing community wastewater treatment facilities to meet Federal requirements under the Clean Water Act. Much of the current use of models—and the perceived need for additional modeling capabilities—at the State level stems from Federal requirements for State action

Large discrepancies between current and potential use for particular issues suggest that State-level model use is limited by some technical or institutional factor (inadequate data, lack of qualified personnel, poor reliability of the model itself, etc.). For example, 34 percent of the States currently use drought and low-flow forecasting models for operations and management, while 67 percent of the States indicate potential uses for them. Resource issue-specific assessments of the States' current and potential model use appear in the section of this chapter entitled: "State Model Use in Individual Water Resource Issue Areas."

Figure 11.—Economic and Social Issues



SOURCE: Office of Technology Assessment.

CONSTRAINTS TO MODEL USE

State agencies were asked to identify problems and needs associated with model development, use, and maintenance in their States, and to recommend ways to solve problems and meet State needs. The responses to these questions ranged from general comments, like "inadequate data" or "lack of qualified personnel," to very detailed descriptions of problems with specific models or programs. The following sections highlight trends encountered in the responses, according to nine subject areas: 1) developing models to meet State needs; 2) data limitations; 3) lack of qualified personnel; 4) access to Federal models; 5) reliability and credibility of models; 6) model standardization; 7) funding; 8) maintenance; and 9) documentation.

Developing Models To Meet State Needs

Respondents frequently recommended that Federal agencies develop models to meet State needs. Many of the respondents identified a need for simple models. Comprehensive models with large data requirements are of little use to States lacking the time, resources, or capability to operate them.

According to the survey, many models cannot be applied to local site-specific problems. Models are often designed to simulate an area too large for State purposes.

Data Limitations

The inadequacy of data was the most commonly identified factor inhibiting State modeling efforts. Not only does insufficient data constrain the development and application of models, but the use of unreliable data can produce inaccurate results. For example, one respondent commented on the impact of using unreliable data for planning advanced waste treatment plants (AWT):

> Millions of dollars have been expended for AWT based on models which had an inadequate data base and the resulting treatment levels required may or may not have been beneficial compared to the costs.

Many of the respondents noted that the reliability and credibility of models is only as good as the input data.

The majority of comments concerning data were general, often simply citing "insufficient data" or "lack of data." The specific responses, however, fall into several categories:

- lack of data for specific stages of modeling (i.e., development, calibration, verification, etc.);
- lack of data for specific issues (i.e., ground water supply, nonpoint source pollution);
- outdated and poorly maintained data bases; and
- unreliable or inaccurate data (e.g., data sampled at the wrong time).

Although the States rely on Federal agencies to supply a substantial part of the needed data, they are and expect to be taking the major responsibility for data collection. The major obstacle in meeting the States' data needs is insufficient funding. Along with funding problems, a shortage of manpower was another frequently mentioned factor limiting data collection.

Several respondents suggested that a central, or possibly a "national" data bank was necessary.

The States also identified four other important, though less frequently cited, data problems:

- poor access to Federal/State data banks;
- no data processing (storage and retrieval) capability;
- duplication of State and Federal data collection efforts; and
- intensive data requirements of many models.

Lack of Qualified Personnel

The States have a severe shortage of personnel qualified to develop, use, or maintain models. This limits State modeling efforts in many ways. For example, some States are unable to modify existing Federal models to suit their specific needs. Other States report that their lack of modeling expertise causes an overreliance on contractors to develop and apply models.

Part of the problem is due to the prevailing salary scales for State employees, which make it difficult to attract and retain qualified personnel. However, most States did not propose supplemental Federal funding, but strongly recommended increased technical assistance and training by Federal agencies.

One respondent wrote the following about the need for training in his State:

> The main problem of model implementation in Indiana is training. The Federal Government should provide the States with low-cost, application-oriented training opportunities . . . .

Training was considered a high priority by the respondents, second only to data needs. Specific concerns about training fell under three categories:

- general education for management-level decisionmakers to understand and appreciate models;
- advanced training for technical personnel to develop, use and maintain models; and
- recommendations for specific courses, e.g., training to use the Environmental Protection Agency's (EPA) Stormwater Management Model.

Although a few States requested funding for training, the majority of the States currently rely on federally conducted training programs. The workshops and seminars held by the Corps of Engineers' Hydrologic Engineering Center (HEC) and USGS were praised by many respondents. One respondent said:

> There is only a handful of people in this State, including the USGS, who can use this type of model (2D—ground water flow model). The training courses in Denver (sponsored by USGS) have been invaluable to us.

The States identified a need for technical assistance at all stages of the modeling effort, from development to maintenance, throughout the range of water resource issues. Most comments were general, like "State needs model expertise assistance (Federal) to expedite solutions." Other States expressed more specific technical assistance problems, e.g., "a lack of technical personnel at regional EPA levels to review and assist the State in model maintenance," or "a strong technical assistance program in ground water modeling technology is needed to provide the capability to establish flexible predictive mechanisms in ground water contamination cases."

Access to Federal Models

An important modeling problem common to many States is the difficulty of obtaining information on or access to Federal models, data, and technical assistance. The States rely heavily on the Federal Government to supply such services to them; improving access to these services represents perhaps the most easily realizable opportunity for the Federal Government to contribute to State modeling efforts.

A majority of the comments on accessibility centered on the need for information about and access to state-of-the-art Federal models. Generally, States are either unaware of, or unable to obtain, models and data to help them solve specific problems.

A periodic report or newsletter was suggested as a means of informing States about Federal modeling activities. Alternatively, the State water resources research institutes could provide a means of transferring information within each State. A national clearinghouse was also recommended by many respondents as a good method to make models available to the States. These centers would inventory available models and provide descriptions to potential users. The clearinghouse could also provide computer programs and documentation to users. Respondents also suggested that a clearinghouse could serve as a center of technical expertise, model maintenance, and quality control.

Reliability and Credibility of Models

Many of the State respondents pointed out that the reliability and credibility of models strongly influences their use. Part of this influence is due to user perceptions. As one respondent stated, "Past experience with awkward models can impede future development." On the other hand, another respondent wrote, "As we use the one model we have, and gain some experience, the reliability and credibility increase."

State respondents also recognized deficiencies in technically measurable aspects of model reliability, in particular, model calibration and validation. Many respondents mentioned problems with the reliability of specific models—a typical comment was, "current ground water modeling programs are not sufficiently sophisticated to model the complex situation (especially the ground water-surface water interface) in this State."

The following concerns were reported as factors affecting the reliability and credibility of models at the State level:

- the degree of uncertainty in results is not communicated for many models;
- the reliability of many models has not been established through repeated use;
- many model parameters are of questionable accuracy;
- assumed values or calculations are sometimes used in the place of field data;
- the state of the art, in some cases, is not advanced enough to provide reliable models;
- some decisionmakers are cautious about model use due to a past history of inappropriate use; and
- model development has been overemphasized in the past, to the detriment of calibration and validation.

Although comments on model calibration, verification, and validation were not numerous, most of the responses had a common theme: the States have an insufficient amount of time, resources, and data to perform these functions.

Specific comments included:

- some Federal agencies have encouraged the use of some models without adequately calibrating or validating them with field data;
- Federal agencies should devote more attention to parameter estimation and testing model sensitivity; and
- a more comprehensive data sampling program is needed for improved validation, and estimates of model accuracy should be developed and provided.

Model Standardization

Various suggestions were given for Federal actions to standardize the modeling process:

- develop standard procedures for model use (e.g., for determining wasteload allocations);
- develop standard procedures for model calibration;
- establish guidelines to govern technical development of models; and
- coordinate Federal data collection efforts to assure standardization and quality control.

When models and model use procedures are not standardized, discrepancies can result if different models are used for the same purpose. One respondent noted that several State and Federal agencies use different models to analyze the same problem—e.g., setting discharge standards. Coordination is needed to avoid conflicting results.

Funding

Many respondents reported that low funding levels limit State modeling efforts. A few States reported that models were not used at all due to low funding. States generally use available funds for adapting existing models (mainly Federal), and have little or no funds available to develop models independently. Several respondents suggested that coordinated Federal-State modeling efforts might improve the cost effectiveness of modeling.

The respondents also reported that funds are needed for:

- computer equipment;
- testing and validating models;
- data collection; and
- personnel and training.

Model Maintenance

From the States' perspective, model maintenance is a minor problem. As most of the models they use are federally built, they rely primarily on Federal agencies to maintain them. States generally seek assurance that Federal agencies will maintain the models they have developed, and will advise States of revisions and modifications.

A few respondents suggested funding States to maintain needed models if Federal agencies are unable to do so. One State cited intermittent funding for model maintenance as a problem. Several respondents recommended seminars as an effective means of informing States of model revisions or modifications.

Documentation

Few respondents reported problems with inadequate model documentation. The few that did typically made a general comment, citing poor documentation as "a barrier to model use."

Specific comments included:

- user's manuals are not written for the average user;
- documentation is not provided for modifications in models; and
- lack of documentation leads to uncertainty about the validity of model results.

STATE MODEL USE IN INDIVIDUAL WATER RESOURCE ISSUES

Surface Water Flow and Supply Issues

Flood Forecasting and Control

Flood forecasting and control models are widely used by State agencies. Most States that indicated a need for flood forecasting models (57 percent of respondents) currently use them for both operations and management decisions (43 percent) and planning and policy (45 percent). Some additional States rely on Federal agency modeling efforts to supply information needs in this area.

Major uses reported for these models include: 1) delineation of flood-prone areas and estimates of potential flood-related damage; 2) evaluation of existing spillway and dam adequacy (under the National Dam Safety Program); and 3) planning/design and operation of flood control facilities. Increased emphasis on nonstructural flood control—e.g., improved flood plain management—in State flood control strategies has made models that delineate flood plains and evaluate the impacts of land-use changes on flooding patterns increasingly important to State efforts. A number of States reported a need for flood forecasting and control models that can analyze small watersheds.

Federally developed models for flood forecasting and control are widely available to the States. Those most frequently mentioned in survey responses were flood control models developed by the Soil Conservation Service and a series of models developed by HEC. The effectiveness of the Corps of Engineers' training program for these models has been a major factor in promoting their use at the State level.

Results from the OTA survey of Federal agencies indicated that model-based information on flood forecasting and control is distributed to State authorities by the National Oceanic and Atmospheric Administration, USGS, and the Federal Emergency Management Agency.

Photo credit: © Ted Spiegel, 1982

Ruins of an apartment building in Johnstown, Pa., testify to the destructive power of raging floodwaters. State agencies widely use flood forecasting and control models to assess the probable extent of flood inundations and to route flows in ways that minimize actual flood damages

Drought and Low-Flow Forecasting

Slightly fewer than half of the States use models for forecasting droughts and low flows, but many States acknowledged that models could be used more extensively. Forty-seven percent of the respondents saw potential applications in operations and management, and 63 percent in planning and policy—the highest reported for any surface water flow issue area. States in every region of the Nation are concerned with drought and low-flow conditions. While Western States reported use or potential use of these models to allocate water and estimate the capability to meet demands, the significance of flow to water quality and wasteload allocations has expanded the potential use of models throughout the country. Eastern States, in particular, emphasized wasteload allocation in discussing potential applications for low-flow models.

A number of Federal agencies provide appropriate models for State use—respondents identified those of the Corps of Engineers, the National Weather Service, and the Soil Conservation Service. Federal agencies also supply States with model-generated information—several States mentioned USGS in this connection. In addition, the National Weather Service provides low-flow forecasting for the States.

Streamflow Regulation

Models for streamflow regulation are currently used by more than half of the survey respondents; approximately the same percentage of States identified potential uses for these models. The State survey showed greater present use of streamflow regulation models than for any other surface water flow issue. The survey also suggested that these models are now employed by most of the States where officials have identified some use potential.

Respondents identified a broad spectrum of applications for such models, including inter- and intra-State water distribution, reservoir operations and dam safety, low-flow effects on wetlands, waste assimilation capacity, flood plain management/flood insurance, and fishery management below dams.

Offstream Use

In many areas of the country, current streamflows and ground water reserves are insufficient to sustain the large withdrawals required for agricultural, industrial, and domestic uses. Projected growth in offstream demand for mining and general economic development will increase conflicts between instream and water quality requirements on one hand, and offstream withdrawals on the other.

Few States currently use models to analyze offstream uses. Those that do, concentrate on planning and policy for projecting future use. Only one State specifically mentioned planning, managing, and operating offstream facilities as an area presently involving the use of models. However, nearly half of the surveyed State officials indicated potential use for offstream models. Determining the availability of water for hydropower, mining, and industrial uses was considered a future area for model use, particularly in the context of comprehensive resource management. Eastern States as well as Western States were concerned with offstream uses.

Irrigated Agriculture

Increasing conflicts with domestic water supply and instream flow needs necessitate sophisticated planning and monitoring to ensure maximum benefits from irrigation water. State agencies employ models to determine current and future supplies and demands, and to determine optimal irrigation schedules to aid farmers in conserving water. Such models are currently used in about one-fifth of the surveyed States; slightly over twice as many States reported a potential for model use. Potential uses include assessing both quantity and quality of surface water, as well as the effects of irrigation on ground water levels. Future uses for irrigated agriculture models include determining water rights, water demands, and stream diversion.

Domestic Water Supply

Domestic water supplies have not kept pace with growing demands. In many localities, supply, treatment, and distribution systems are inadequate, resulting in shortages and reduced water quality. Comprehensive management for conservation, and multiple-objective planning, will become increasingly necessary as further growth occurs in water-short areas.

Current use of models by States focuses on projecting present and future supplies and demands, and designing supply systems to meet future demands. Slightly under one-third of those surveyed use water supply models. Approximately twice as many indicated potential for model use, primarily for assessing the relationship between water supplies and water quality requirements. A few States indicated a need for models to analyze the efficiency of existing distribution systems.

Instream Flow Needs

Models for assessing instream flow needs serve a variety of purposes at the State level. Their use in planning and policy to meet instream flow needs for fisheries, recreation, and hydropower was reported by 37 percent of the States—an additional 24 percent indicated the potential for such use. Fifty-five percent of the States acknowledged a potential need for operations and management models, although only 12 percent currently use such models.

Instream flow models are becoming increasingly important as tools for setting minimum instream flow requirements. The models have further application for meeting water quality standards and allocating water. A few States cited data limitations as constraints to current use. Assistance in using these models is supplied by the Fish and Wildlife Service's Instream Flow Group, the Corps of Engineers, and USGS.

Water Use Efficiency and Conservation

Little is currently known about the extent to which demands for water could be reduced through the use of conservation techniques or improved management and planning. However, potential benefits in reduced expenditures for supply, treatment, and distribution systems were sufficient for one-fourth of the States to indicate a potential use for models in researching these problems. This represents the greatest State interest in models for research purposes among all surface water resource issues.

Under 20 percent of the States surveyed currently use models in this area, although close to half indicated potential uses for such models. State use focuses on models for predicting demand, and basic water accounting models similar to those used in determining available supplies for agricultural, domestic, and other offstream and instream uses. Greater existing and potential use was reported for planning and policy purposes than for operations and management.

Surface Water Quality Issues

Urban Runoff

State officials reported high potential for model use to determine water quality problems stemming from urban runoff, despite low levels of current use. Two-thirds of the States saw continuing or possible future uses for such models in planning and policy analyses, and 55 percent envisioned uses for operations and management decisions. Several States suggested that the credibility of existing models has limited their use.

The comprehensive planning provisions of section 208 of the Clean Water Act figure largely in State reports of existing and potential uses for urban runoff models. Models are currently used to develop control measures; to plan, construct, and maintain storm overflow facilities; and to research and predict local urban runoff problems. Problems of site-specific adaptability and excessive complexity in current models were mentioned by a number of respondents. Respondents indicated that simple models for site-specific calculations could increase model use in this area, even though such models may not be suitable for complex runoff problems.

Erosion/Sedimentation

A number of States indicated the need for improved erosion/sedimentation models as a priority in water resource management. Of the State respondents, 53 and 69 percent saw potential uses for these models in operations/management and planning/policy, respectively—approximately 2½ times the current level of use.

Many States reported current and potential model use under section 208 of the Clean Water Act.

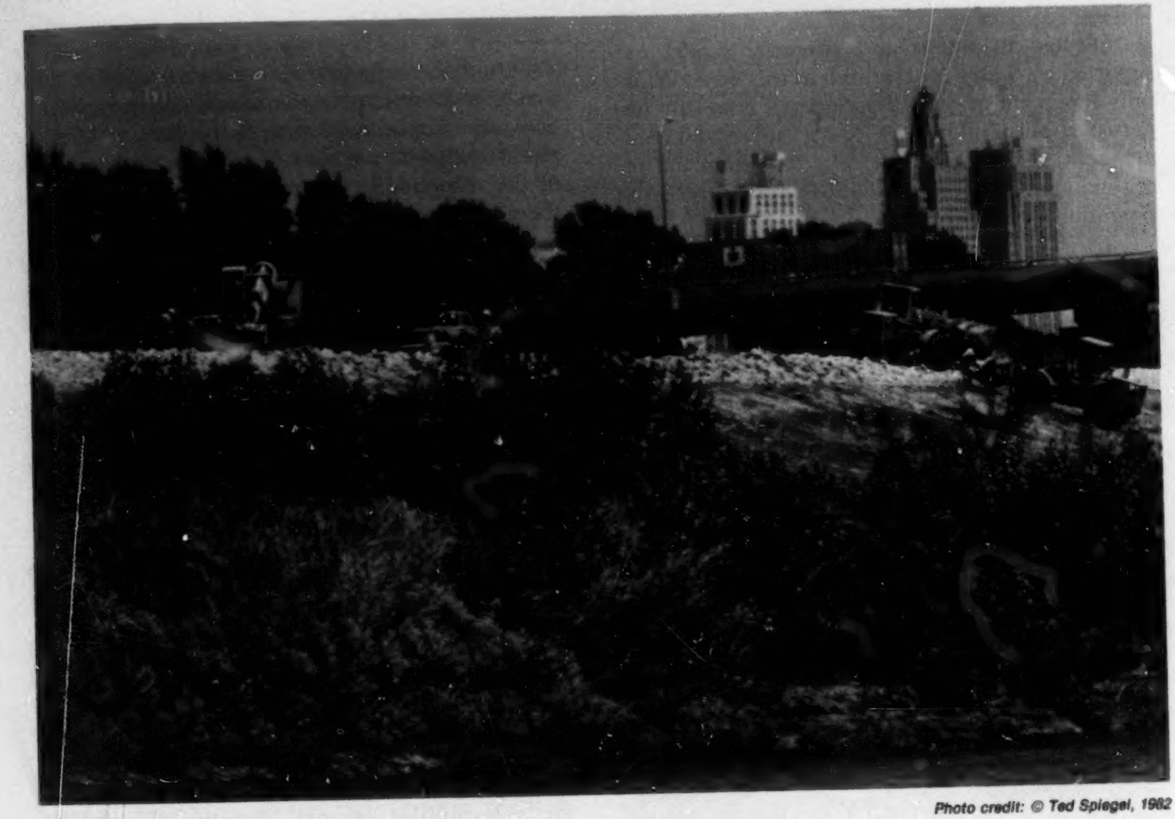


Photo credit: © Ted Spiegel, 1982

Earthmoving equipment near a riverbank in Kansas City, Mo., alters the land's contours to minimize the erosive effects of runoff from nearby highways and other urban sources

USGS and the Soil Conservation Service were repeatedly cited as providing models or working jointly with States to determine erosion and sedimentation effects.

State officials reported a wide variety of potential uses for erosion/sedimentation models; among these are evaluating erosion control measures, determining canal and reservoir sedimentation rates, evaluating irrigated and nonirrigated agricultural land uses, and planning for urban development.

Salinity

Salinity models do not appear to have a high priority in State-level water resource management. Less than half the State respondents identified potential uses for such models, and only 6 percent currently use them for operations and management decisions. Potential uses include: 1) determining the ecological benefits of salinity reduction; 2) implementing State ground water laws; 3) monitoring effects of pesticides and residuals; and 4) monitoring inland streams receiving brines from saltwater sources.

Agricultural Runoff

One-third of the States currently use agricultural runoff models for planning and policy, and nearly double that figure—57 percent—anticipate potential uses. A number of States use models in connection with section 208 of the Clean Water Act; others specified future uses in planning and regulation of animal wastes as well as in developing and implementing fertilizer and pesticide management plans.

Concern over the effects of agricultural runoff is reflected in actual and potential model use reported by States for research in this area. While only 8 percent of State respondents presently use agricultural runoff models for operations and management decisions, 14 percent use them for research, and 27 percent identify future research potential for such models.

Airborne Pollution

Several of the comments indicated that some respondents misinterpreted this question. These respondents may have identified model use for State air pollution control, rather than for the specific purpose of determining the effects of airborne pollution on water quality. However, two States identified potential use of models for acid rain abatement.

Wasteload Allocation

States use models extensively for determining wasteload allocations. Two-thirds of the State respondents indicated present use for operations and management decisions, and 57 percent reported current use in planning and policymaking—more than for any other water resource-related purpose. Survey responses suggested that the relatively long history of model use in this area has made these models widely available to States. Most States that recognize potential uses for these models are presently using them. The ubiquity of wasteload allocation problems, and the expanded State role in water pollution control, has contributed to widespread wasteload allocation model use. Model use was specifically mentioned for implementation of sections 201, 208, 303, and 402 of the Clean Water Act.

Many States, however, stated that these models need refinement. Further validation of reaction rates and other necessary parameters, standardization of models for different geographic regions of the country, and evaluations of the magnitudes of error in predictions, were among the improvements suggested. Several States also identified the need for standard wasteload allocation models for the following purposes: evaluating the effects of discharges into nontypical streams (swamps, estuaries, and intermittent streams), designing standard waste treatment facilities, and determining the need for advanced waste treatment.

Thermal Pollution

State water resource professionals reported that available thermal pollution models are simple and accurate. About one-fourth of the surveyed States reported current use of such models, and about half of the respondents recognized potential uses for them. A number of States noted that all necessary thermal modeling under section 316(B) of the Clean Water Act is performed by power-generating or other industries, and is merely reviewed at the State level. Others cited the Corps of Engineers, EPA, and USGS as providing thermal modeling services for States or in conjunction with State efforts.

Toxic Chemicals

Many States identified the development of models to deal with toxicants as a top priority, with significant potential for future applications. As with other recently recognized problems, about one-fourth of responding States identified a need for such models in research, although few of the respondents currently use them for any purpose. Potential uses, both for operations/management and policy/planning, were identified by 55 percent of the surveyed officials.

Respondents indicated that models are needed for determining sources of toxicants, toxicant transport and removal mechanisms, and for setting toxic chemical effluent standards. Some States identified data availability as a limiting factor in modeling.

Drinking Water Quality

About half the States reported potential uses for drinking water quality-related models, primarily to assist in setting standards required under the Safe Drinking Water Act. States also noted uses for improved models in determining the effects of wastewater discharges on drinking water quality, as well as for specific problems such as the effects of mining and low flows. A small number of States indicated that these models were of high priority; fewer than one-fifth of the States indicated that they are currently used.

Water Quality Impacts on Aquatic Life

Several States stressed the need for further research and improved modeling techniques to gage the effects of changes in water quality on aquatic life. Credibility problems of current eutrophication models were specifically mentioned. Survey comments suggested that improvements to aquatic life impact models are of major concern to respondents throughout the country.

Sixty-nine percent of surveyed State officials identified potential application for these models in planning and policymaking; 55 percent identified future operations and management uses—in both cases about twice the existing level of use. Officials identified a variety of uses for aquatic life impact models, including evaluating permit applications, pollution control program planning, and comprehensive basin planning.

Ground Water Issues

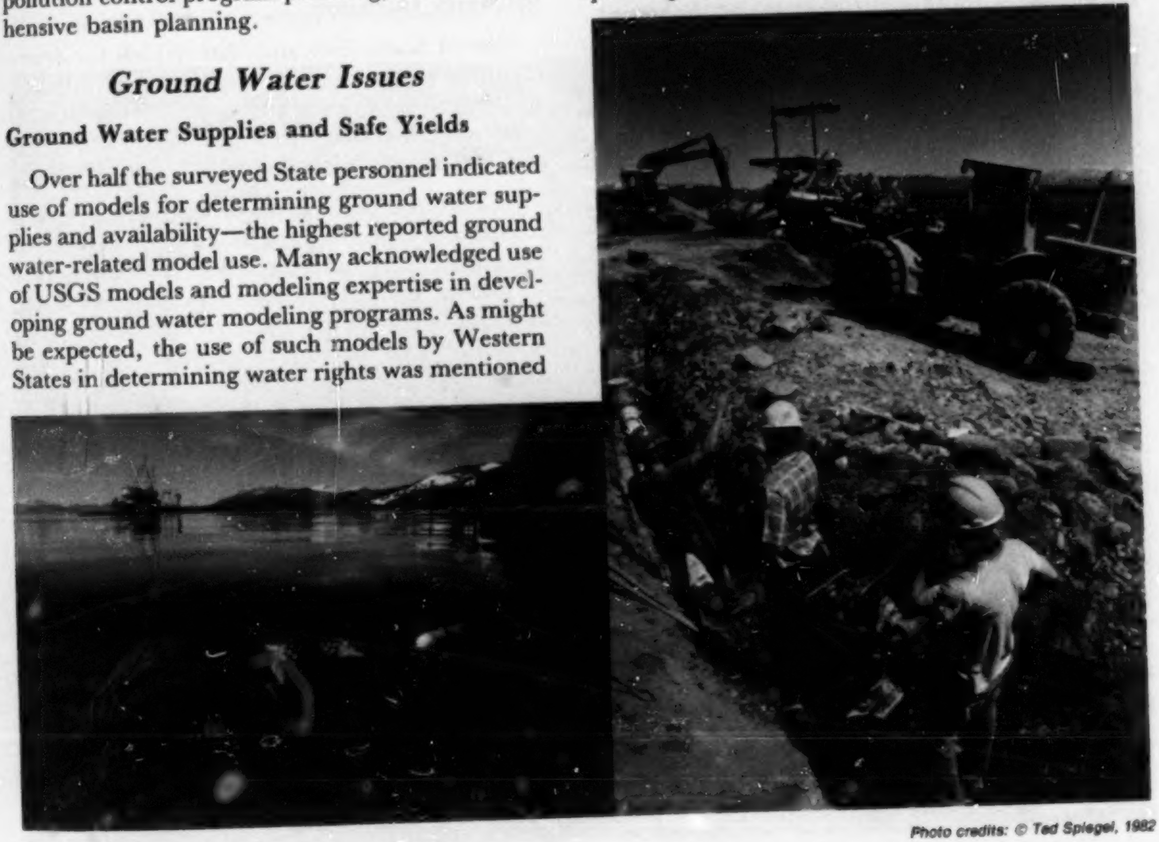
Ground Water Supplies and Safe Yields

Over half the surveyed State personnel indicated use of models for determining ground water supplies and availability—the highest reported ground water-related model use. Many acknowledged use of USGS models and modeling expertise in developing ground water modeling programs. As might be expected, the use of such models by Western States in determining water rights was mentioned frequently; however, ground water supply model use was equally evident for Eastern States.

Ground water supply models are presently employed by most of the States that reported some use potential; however, many States place a high priority on improving these models. The lack of historical aquifer performance data and the extensive current data requirements of ground water models were repeatedly cited as hindering State modeling efforts.

Conjunctive Use of Ground and Surface Water

A higher percentage of survey respondents reported potential uses for models of the interaction



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Lake Tahoe, Nev., has long been billed as one of the world's clearest bodies of water. Rapid development along shorelines, however, has greatly increased the flow of nutrients into the lake, accelerating natural eutrophication rates, creating nuisance algal growths, and endangering Tahoe's ecological balance. Models have been used both to assess the effects of development and to evaluate the effectiveness of centralized sewage treatment in preventing the eutrophication process. In underwater labs above, University of California biologists and hydrological scientists use radioactive trace elements to monitor nutrient levels in the water. Meanwhile, crews build sewage transport facilities to divert wastes around Lake Tahoe for treatment and release in less sensitive areas between ground water and surface water than for any other ground water-related issue. Such models are valuable for developing comprehensive basin plans and for comprehensive water supply management. Over 35 percent of the surveyed States currently employ conjunctive use models—after supply and safe-yield models, they are the most extensively used model for ground water management. Some States reported using models developed by USGS; a number of others observed that the lack of field data constitutes a bottleneck to using these models.

Accidental Contamination of Ground Water

Although over half the States indicated potential for future use of models that predict the spread of contaminants in ground water, fewer than 10 percent currently employ them. Gaps in current knowledge about the behavior of contaminants in some types of ground water systems and data limitations upon the construction and validation of such models hinder more widespread use. Survey respondents envisioned such future applications as determining effects of various pollutants and requirements for control measures, devising warning systems for the public, and predicting longer term contamination.

Agricultural Pollution to Ground Water

Determining the effects of agricultural pollutants on ground water is also a modeling area where reported potential for State-level use is high, although a low percentage of States currently use models. Seventy-one percent of the surveyed State officials saw potential uses for such models in planning and policymaking, and 57 percent envisioned operations and management uses—current uses amount to less than one-sixth of these potential use levels. The officials specified potential uses for these models in section 208 planning, determining effects of various contaminants and corrective measures, planning allowable point source pollutant loads, and supplemental monitoring for regulatory purposes. A number of States indicated that data on pollutant movement is a limiting factor in model development and use.

Ground Water Pollution From Waste Disposal

Survey respondents indicated that lack of data and poor understanding of ground water chemistry are primary limitations on States' abilities to model the spread and effects of pollutants to ground water from waste disposal sites. Limited understanding of the reactions and diffusion of pollutants in mixed geological formations, and deficiencies of data for validation purposes, were cited as specific problems. While potential uses were reported by a high proportion of State officials—71 percent for planning and policymaking, 59 percent for operations and management decisions—these models are currently used by only one-fifth as many States. Anticipated uses include determining infiltration from sanitary landfills and mine waste disposal.

Saltwater Intrusion

Several States indicated that models for determining saltwater intrusion to ground water supplies are water resource management priorities; however, interest is naturally limited to coastal areas and States with major inland saltwater bodies.

The acquisition of sufficient data to verify such models was repeatedly cited as a significant need. State officials envisioned several management uses for these models, in particular establishing recharge areas, as well as determining acceptable pumping rates and designing well fields.

Economic and Social Issues

Effects of Pricing on Use

Models that evaluate the effects of pricing on water use were seen as having potential planning and policymaking uses by 59 percent of the State survey respondents. Respondents referred to comprehensive planning efforts under title III of the Water Resources Planning Act and section 201 facilities planning under the Clean Water Act as areas in which models are needed. Some States suggested that current models are not precise evaluation tools, and that their importance may be limited to places where strict conservation and reuse laws apply. Models are currently used by a small proportion of surveyed States, primarily in planning and research.

Costs of Pollution Control

Slightly fewer States indicated a need for models to evaluate pollution control costs than for most other types of social and economic modeling. Suggested potential uses include assessing the effects of alternative waste treatment strategies on firm behavior, and determining the impacts of pollution control costs on individual industries. At present, such models are used in only a few States.

Cost/Benefit Analysis

Use of cost/benefit analysis models for planning and policymaking was envisioned by over half the State officials; 23 percent of those surveyed currently use such models for planning. Some current users noted, however, that models evaluating the cost effectiveness of alternative actions are more applicable than cost/benefit models. Several respondents consider the cost/benefit concept too subjective to be adequately modeled. A number of States indicated that improved models for cost/benefit analysis would be highly desirable, and one respondent specified a need for a combined hydrologic/economic model for cost/benefit studies.

Regional Economic Development Implications

Models for evaluating economic implications of water resources development and policy are used by States in the context of planning efforts under section 208 of the Clean Water Act and title III of the Water Resources Planning Act. Slightly fewer than one-half of the surveyed State personnel predicted future uses for these models; 22 percent indicated current planning uses. Officials mentioned

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The Cuyahoga River was once infamous as an industrial sewer, reaching national attention as the river that burst into flames. But over the past decade, the Cuyahoga has experienced a dramatic turnaround as industries along the river, like this Republic Steel facility in Cleveland, Ohio, made significant capital investments in effluent processing equipment. EPA uses models that determine costs of pollution control, as well as effects on such factors as prices of finished products, future industrial activities in the region, and employment levels, in analyzing proposed cleanup and treatment regulations such specific uses as predicting population and economic growth in water-short areas, comprehensive river basin planning, and determining the effects of ground water depletion.

Forecasting Water Use

Forecasting water use with models was considered possible at the State level by 59 percent of survey respondents; 31 percent currently use such models for planning and policy purposes. Some States doubt the reliability of these models in their current forms, and suggested that existing data are inadequate to justify sophisticated model forecasting. A variety of applications are projected for improved models; ensuring that water quality standards are not violated due to overallocation of supplies, and evaluating existing laws regulating ground and surface water use were repeatedly mentioned, as well as simple projections of future demand.

Social Impact

Relatively few States indicated a need or potential use for social impact models. While one State official suggested development of a general model that could be calibrated to local conditions, little State-level interest in such models was expressed, and some respondents questioned their reliability.

Risk/Benefit Analysis

State officials reported a variety of potential uses for risk/benefit analysis models, including dam safety analysis, flood management, and toxic waste management. Slightly fewer than half foresaw future planning and policy uses for these models in their States; 10 percent currently employ them.

Competitive Water Use

Fifty-nine percent of the surveyed officials indicated the possibility of future planning and policymaking applications for models of competitive water use; one-fifth reported that such models are currently used by their States. A few States reported that these models are a high priority for analytical work. Reported potential applications include: basinwide water supply planning, water rights determinations, and the evaluation of conflicts between water supply and water quality objectives.

Unified River Basin Management

Models for unified river basin management are currently used by a greater percentage of States than any other socioeconomic model: one-third of the survey respondents indicated that such models are currently employed for planning and policymaking, and nearly twice as many foresaw future use potential. State-level personnel mentioned such uses for these models as regional water supply planning, integrating water quality considerations with basin development, planning studies to evaluate different management options, and planning and control of development.

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Modeling and Water Resource Issues

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Chapter 6

Modeling and Water Resource Issues

Government agencies normally use water resource models to address specific resource problems under their jurisdiction. While most problems and model applications have unique aspects, it is possible to generalize about the kinds of problems most frequently encountered in water resource management—and the analytic techniques used to understand them. This chapter describes 33 of the Nation's most prevalent water resource issues, briefly assesses the modeling capabilities associated with each of them, and evaluates the model types used to analyze them. Previous chapters have focused on generic issues and problems involving water resource models; this chapter deals with specific water resource concerns and the capacity of models to address them. It is provided as a layman's introduction to the relationship between models and real-world water resource issues.

Water resource concerns can readily be grouped according to four major subject areas: 1) surface water flow and supply; 2) surface water quality; 3) ground water quantity and quality; and 4) economic and social models. The areas differ significantly with regard to levels of current knowledge, kinds of issues addressed, and types of models and levels of modeling expertise currently available. Each is discussed in a separate section of the chapter.

The first three subject areas deal primarily with physical processes, and are described according to a common format: 1) introduction; 2) types of models; 3) issues addressed; and 4) evaluation of currently available models. Each subject-area model evaluation follows a format that reflects the problems addressed, processes modeled, and mathematical techniques most commonly used within each scientific discipline. The last area, economic and social models, deals with the social science information needed to support water resource decisionmaking. Models of social sciences processes differ fundamentally from those of physical processes, and are extremely diverse; consequently, a larger subjective component is involved in evaluating them. No formal evaluation of economic and social models was undertaken for this study.

SURFACE WATER FLOW AND SUPPLY

Introduction

Managing surface water today virtually requires the use of a wide range of computer-based analytical techniques, ranging from sophisticated models that forecast the probable frequencies and extents of serious floods, to relatively simple computer models for simulating the operational characteristics of farm irrigation systems. All of these models provide information to help assure that water will be available when and where needed, or will not intrude when or where it is not wanted. Models permit the analyst to: 1) make reasonable *predictions* of natural events, and 2) estimate the favorable and adverse *consequences* of man's attempts to improve the reliability of freshwater production, distribution, and use systems.

Water resource models are widely applicable to problems in policy, planning, operational management, and regulation of the Nation's surface water resources. Existing models are widely used to *plan* and *operationally manage* most water availability and water use problems. Model use is not as common for policy and regulatory activities, partially because existing models are not well adapted to decisionmaking in these governmental areas, and partially because such decisions have traditionally been based more on qualitative than quantitative criteria.

Models used to analyze surface water flow and supply problems can be subdivided into two broad categories, for which both current model capabilities and future promising roles are somewhat different. For each of the two broad categories—water availability and water use—four specific problem areas are discussed later in this section. Although these problem areas are not all-inclusive, they encompass the major surface water quantity problems facing the Nation. Each problem area is specific enough to permit discussion of successes and failures in the use of models, and development of recommendations for appropriate model uses. An evaluation table for the models used in each problem area is presented later in this chapter (see table 7).

To introduce the modeling techniques that apply to surface water flow and supply issues, applicable model types are discussed below. Generally, the model types are not limited to one specific problem area—each model type may be applicable to several issues. References, keyed to over 30 model classes, are provided in appendix D to this report.

Availability of Water

Water availability analysis—which encompasses but is not limited to the sciences of hydrology and meteorology—uses models extensively. While models are less frequently used in policymaking than for planning and management, numerous examples of model use for determining water availability can be cited throughout private industry and at all levels of government. In fact, a major problem in using models to analyze a given water availability problem is the difficulty of selecting—from among the plethora of available models—the most appropriate model for the problem at hand.

Determining the availability of surface water requires analyses of the *hydrologic cycle,* typically including calculations of streamflow magnitude, duration, and frequency; and the temporal and spatial variations of these streamflow characteristics. A specific problem may require analyzing one or more of these characteristics at a single point along a stream—for instance, to determine the extent of a flood plain—or it may require coordinated analysis at a large number of locations in a watershed (e.g., to operate a series of multiple-purpose reservoirs).

Solving problems of water availability, however, requires more than understanding and modeling the hydrologic cycle. Many problems arise because of the need to *alter natural hydrologic processes* for a variety of reasons: to reduce flood hazards; to reduce the risks of drought and low streamflow; to change the timing and distribution of streamflow; and to improve management of this increasingly scarce renewable resource for a variety of beneficial purposes. Certain types of human intervention in natural hydrologic processes can be modeled reasonably well, but many types of modifications and controls introduce conditions that may be too complex to simulate or forecast accurately. In dealing with water availability problems, one must distinguish between the capability to model *natural proc-*

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The area surrounding Otter Creek in Vermont's Green Mountain National Forest is typical of the many protected watersheds that play an important part in assuring adequate supplies of water for such purposes as human consumption, recreation, and protection of aquatic and terrestrial life. Models of watershed processes describe water flow from the time precipitation reaches the Earth until it reaches a lake, stream or ground water aquifer, or evaporates into the atmosphere. Such information is used to estimate regional water supply, and can also be used to estimate the magnitude of floods *esses,* and current capabilities to model the *effects of human management* efforts on these processes.

Water Use

Models have been used less frequently to analyze water use than to analyze water availability. Except for agricultural irrigation needs in arid areas of the Western United States, water availability has historically been so much greater than water use that there was little or no requirement for sophisticated analysis. Consequently, almost no effort was expended on developing models to analyze water use. In recent years, however, increasing demand for relatively large quantities of water—e.g., for energy development—and the droughts of the 1960's in the Northeast and the 1970's in the Midwest and West, have stimulated the development of models for planning and operations/management. Nonetheless, these recent developments are not yet reflected in widespread adoption of water use models.

Water availability and water use also differ in the kinds of information they require for model construction. Most problems of water availability are concerned with physical principles and relationships that are reasonably well understood, and are consequently easier to model successfully, while most water use problems involve not only physical factors but also *social and economic factors*—many of which are less well understood. The lack of knowledge about interrelationships among economic, social, and physical factors is compounded by a lack of data on social and economic factors related to water use. Social and economic models are discussed in more detail later in this chapter.

Types of Models Used in Surface Water Flow and Supply Analysis

Of the wide array of models used to analyze various aspects of surface water flow and supply, the most important ones fall into two broad model classes—*process* models and *statistical* models. Process models simulate or describe the flow of water through a watershed or water body using known, physical relationships. Statistical models use empirically derived relationships—often with no inherent physical meaning—to estimate the probability of a flood or drought, the magnitude of a flood peak, or even regional water use demands.

Watershed Process Models

Watershed process models follow the movement of water from the time it reaches the Earth as precipitation until it flows into a lake or stream, reaches a ground water aquifer, or evaporates back to the atmosphere. Models used to describe the dynamics of water over three distinctly different types of land areas are described in this section: 1) watershed simulation models, which describe the movement of water over large, nonurban areas; 2) agricultural soil/water interaction models, which are designed to specifically address agricultural water problems; and 3) urban runoff models, which describe the movement of water through urban areas.

Watershed Simulation Models.—Simulation models describing the movement of water over large, nonurban areas are used to estimate flood peaks, low flows, and volumes of water available to users. They are most useful where historical streamflow data are sparse or nonexistent. These simulation models are powerful planning tools that come far closer to replicating measured flows than was previously possible. Four types of processes must be included in watershed simulation models: 1) the movement of rainfall into and through the soil; 2) ground water flow to streams (called baseflow); 3) the loss of water to the atmosphere from evaporation and evapotranspiration from plants; and 4) in colder climates, snow accumulation and snowmelt.

Watershed soil/water process models are used to replicate water movement into and through the soil for: 1) estimating flood peaks during storm events; 2) estimating water supply on an annual basis; and 3) estimating low flows during dry periods. Current models are most reliable for estimating low flows and total annual runoff volumes, and less so (but still acceptable) for calculating short-term flows and flood peaks.

During low-flow periods, except in very humid climates, water enters streams primarily by seepage through the soil profile or from aquifers. Most *baseflow models* do not use advanced ground water modeling techniques to estimate flow rates, but rather use observed flow patterns during long dry periods as an estimate of ground water flow to streams. They are quite adequate for estimating baseflow during floods, and reasonably good for estimating low flows.

Evaporation from water surfaces and *evapotranspiration* from plants are modeled to simulate the soil-drying process. The drier the soil, the more precipitation will infiltrate and be stored during the next storm. The results are more reliable for watershed-wide average soil moisture than for specific locations within the watershed, but are difficult to validate because of the scarcity of field data.

For areas where snow remains on the ground for more than about a month, the processes of *snow accumulation* on the ground and *snowmelt* in the spring must also be considered. Total runoff volumes from snowmelt can be simulated quite well for forecasting water availability during the following summer, but models are not very reliable for simulating snowmelt flood peaks (magnitudes are bad and timing is worse), because of the difficulty of predicting spring weather conditions. However, in areas where the snowmelt occurs relatively slowly, the models are adequate for most purposes.

Agricultural Soil/Water Interaction Models.—Simulation models similar to the watershed process models described above have been developed to assist in agricultural water conservation. Four types of models are currently available:

Soil/water process models are sometimes specialized to estimate moisture conditions in a small plot, rather than average conditions over an entire watershed. These *plot-size soil/water process models* are used for agricultural water management and land-use decisionmaking. This approach has potential for improving crop management decisions, but these models are not yet very accurate.

Models that analyze the effects of local climatic variation on *plant water use* are valuable for allocating available water supplies. Acceptable results are obtained on an annual or seasonal basis, but estimates of shorter term demands (less than 1 month) are unreliable.

The extent and duration of the soil's capacity to hold irrigation water for plant use has been modeled to assist in farm water management and irrigation system design. Results from *irrigation water demand models* are generally reliable for estimating average annual water use, but poor for estimating how use is distributed over the irrigation season.

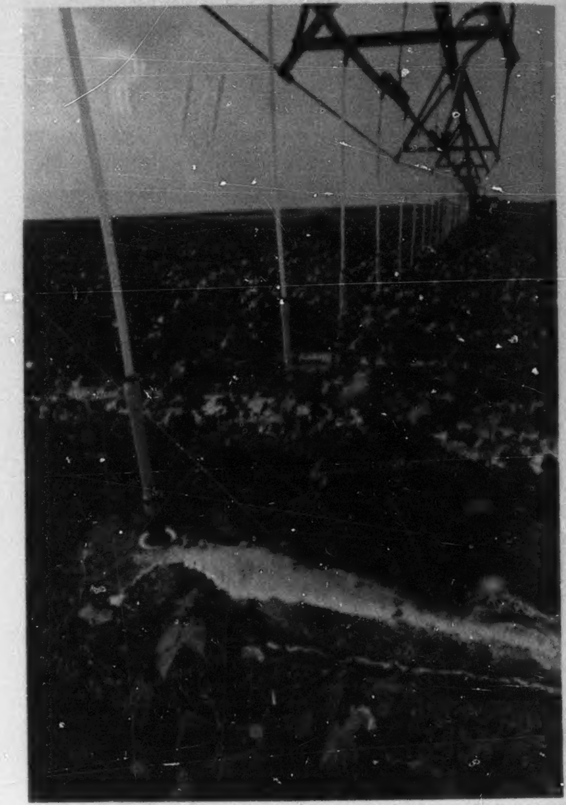

Photo credit: © Ted Spiegel, 1982

Drophead nozzles on this central pivot irrigation system in the Texas High Plains deliver water directly to plant root systems, cutting down on transpiration losses, and reducing water use by up to two-thirds over conventional irrigation systems. Models have found extensive use in irrigated agriculture, performing such tasks as determining the extent and timing of crop water needs, and planning, designing, and operating irrigation water distribution systems

In areas where excess water is a problem, soil moisture can be reduced by subsurface tile or ditch drains to make the land more productive. *Land drainage models* estimate flow rates for system design and residual field moisture conditions for cropping decisions. These models achieve adequate to good results.

Urban Runoff Models.—Urban runoff models generate simultaneous flows from many small urban watersheds, and aggregate them into flood flows for specified downstream points. These models are sophisticated tools for urban flood plain management and for designing and operating urban storm-water control systems. They have received widespread use over the last few years and promise a great deal for the future.

Stream Process Models

Stream process models begin describing the movement of water at the point where watershed process models end—once the water enters a stream, lake, or reservoir. In this section, two topics are discussed: 1) models that describe the flow of water through streams, lakes, and reservoirs, used primarily for flood control; and 2) models that describe the movement and erosion of sediments (called alluvial processes) within water bodies.

Channel Process Models.—Channel process models describe the flow of water through streams, lakes, and reservoirs. They are often used for reservoir operations during flood conditions and for flood plain management. In general, they provide very reliable results when accurate information on channel and flood plain geometry is available. The following models are included in this category:

Flood channel routing models are used for operating flood control facilities or issuing warnings during flood emergencies. These models provide quite reliable estimates of changes in flow depth and velocity as water moves downstream in well-defined channels. However, the estimates are less accurate for larger floods where streams overflow their banks, and are particularly unreliable where flows spread out over large flat areas.

When flows enter a lake or reservoir they increase both water depth and outflow through spillways or other outlet controls. *Lake and reservoir routing models* are accurate enough to size spillways to ensure dam safety and for controlling spillway gates to minimize downstream flood damage.

Flood plain management relies heavily on accurate mapping of flood hazard areas. Models can estimate flood heights and—when combined with accurate topographic maps—the geographic extent of flooding. The most accurate results from *flood inundation models* are achieved when the stream flows between stable channel banks, and the least reliable estimates are obtained on broad flat flood plains where flows are deflected by small obstructions and are spread in random patterns from one event to the next.

Special channel routing models are used to determine the downstream areas that would be inundated if a dam failed. The reliability of *dam failure models* is uncertain, because few historical records are available on the hydrologic conditions existing at the time of failure.

Alluvial Process Models.—The dynamics of channel erosion and sediment deposition have been described through modeling techniques. The results, however, are approximate, and a great deal more research is needed to make these models reliable. Two important problem areas include reservoir sedimentation and channel erosion:

Reservoir sedimentation models have been developed for determining the amount of sediment washed into a reservoir that is deposited on the bottom, thus reducing its water storage capacity. These models do not have the accuracy desired for estimating useful reservoir life, unless supported by empirical relationships from reservoir surveys.

Flowing water can erode the channels through which it flows and deposit sediment loads downstream. Problem locations can be identified by using *channel erosion and deposition models,* but the results are not reliable enough for channel design or maintenance management.

Statistical Models

When causative mechanisms are not well enough understood to construct process models, or the expense of developing or using process models is not justifiable, statistical models are often used in their place. Statistical models can be used whenever enough data are available to estimate the relationships between factors of interest—without having to understand the underlying physical processes.

Three types of models are presented in this section: 1) statistical flood models, which yield results similar to combined watershed and stream process models; 2) flood and drought frequency analysis, used for sizing flood control or water supply projects; and 3) water use statistical relationships, which are used to estimate demands for water.

Statistical Flood Models.—Statistical models—simpler in approach than the process models discussed earlier—have been developed to estimate flood flows and areas of inundation. These tools are useful for structural design or reservoir operation in situations where more sophisticated continuous simulation models are not justified. Three common approaches—flood formulae, regional flood formulae, and unit hydrograph models—have been extensively used.

Flood formulae are simple equations for estimating flood peaks from watershed characteristics. They have been used for years to help design small structures, but can only be recommended for relatively small projects. Much more reliable for structural planning are *regional flood formulae*. These equations are derived statistically using historical data and can be used for estimating flood peaks on streams throughout hydrologically uniform regions.

Another approach, called *unit hydrograph modeling*, is based on the assumption that a given amount of runoff from a given watershed will always result in similar flood patterns. These models have long been used to establish flow patterns for designing flood control reservoirs. The results are reasonable for reservoir design to prevent flooding by a storm event of specified size, but less than desirable for reservoir operation.

Flood and Drought Frequency Analysis.—Several approaches are available for estimating the frequency of occurrence of floods and droughts. The purpose of these models is to determine the economically optimal size of flood control or water supply projects. The available statistical models provide reasonable to good results for most applications.

Flow frequency models analyze historical series of flood peaks, flood volumes, or low flows to provide an estimate of the maximum or minimum flow magnitudes to be expected, on the average, no more than once every 10 years, 100 years, or some other period. The reliability of these models improves with longer record lengths. Once the statistical characteristics of streamflow have been determined, *annual data generation models* can generate annual runoff sequences that match the size, probability distribution, and other patterns of historical flows for use in determining reservoir capacity. The results are generally good for monthly, seasonal, or annual time periods.

Another important use of statistical models is for assisting reservoir design. By accounting for all inflows (stream and precipitation) and outflows (evaporation, uncontrolled releases, and project water delivered) over long time periods, capacity requirements for designing reservoirs and rules for operating them during dry periods can be determined. *Reservoir water accounting models* provide excellent results if reliable data are available to describe inflow and storage volumes.

Water Use Statistical Relationships.—Water use demands (use as it would be if unconstrained by supply shortages) are estimated either from historical data or simulation models. Two types of models have been applied on broad regional scales:

Regional water use relationships statistically estimate peak, annual, and seasonal variations in water use rates. Their results are generally adequate for estimating the volume of water needed over long periods, but not for estimating peak demands.

Annual use generation models, similar to models that simulate streamflow, have potential for generating estimates of monthly to annual water use. These results may then be combined with supply estimates for the same period to improve water supply reservoir design or operating procedures. However, reliable models of this type are not widely used.

Water Availability Issues

Flood Forecasting and Control

Floods rank among the most prevalent of natural hazards. About half of the Nation's communities, and nearly 90 percent of its largest metropolitan areas, are located in flood-prone areas. Despite expenditures of more than $13 billion for flood control over the last 50 years, flood damage continues to rise each year. Residential, commercial, and industrial development in flood-prone areas outstrips our ability to provide protection, while the economic value of existing damage-susceptible property increases as well.

Available models and the hydrologic data required to operate them are generally adequate for flood control planning and management. Even in situtations where hydrologic records are not as extensive as designers require, statistical methods and digital simulation models provide sufficient information for designing flood control and protection structures.

Although there are isolated cases of design deficiencies in flood control projects, most of the hundreds of existing projects function as planned. When flood damage occurs in "protected" areas, it is generally not due to faulty flood forecasting or to failure to operate flood control projects properly. Rather, damages occur because the flood magnitude exceeds the degree of protection provided by the project. However, when flood magnitudes exceed the project's protective capabilities, accurate forecasting becomes essential for *minimizing* loss even if it cannot *prevent* loss. A poor forecast of a flood exceeding the control structure's capacity can cause serious mismanagement, and greatly increase the resulting damage. Improvement is needed in the accuracy with which flood characteristics are predicted once the event is under way.

While models and predictive methods for flood control planning and management are generally satisfactory for design, engineering, and routine operation of traditional areawide flood control structures, flood control planners are increasingly concerned with nonstructural measures for reducing flood damage. Consequently, new needs for models and data aimed at nonstructural approaches have arisen. Many of these measures are regulatory in nature, and frequently address areas considerably smaller than those associated with larger scale structural projects. As a result, many traditional flood control models are not suited for planning and managing nonstructural approaches. These traditional models are based on a "macrohydrologic" scale, in which model assumptions and data requirements are scaled to hydrologic analyses for relatively large watersheds. However, when these models are applied to the "microhydrologic" scale, they are often found to be inappropriate, either because detailed data are not available at the microscale level, or because the macroscale assumptions are not consistent with conditions on the smaller scale.

Good hydrologic analysis on a microscale basis requires considerably more data than macroscale analysis; consequently, geographic consistency in data on soil types, vegetation, land use, precipitation, and surface runoff is considerably more important in microscale analysis. As a result, the models being developed for microscale analysis frequently depend on the availability of spatial data bases—i.e., sets of computerized "maps" with a geographically consistent set of data on an area's physical characteristics. Although the needed data are frequently available on printed maps, the effort required for digitizing and maintaining the data significantly limits widespread use of these models at present.

Model use for the regulatory aspects of flood control has been extensive in both flood plain management and flood insurance programs. Two basic types of models—flood inundation models and flood frequency models—have been widely employed. Flood inundation models are used to delineate flood hazard areas. When properly used, the available models are relatively noncontroversial. However, problems have occurred when the analysis is performed for part of a stream at one time and for adjacent parts at another time, with the result that the flood hazard areas fail to coincide at the boundaries of adjacent areas. Since the primary purpose of this analysis is regulatory in nature—identifying areas subject to flooding so that appropriate restrictions in use can be implemented—it is not surprising that even minor inconsistencies in flood hazard area delineations are major sources of controversy.

A larger source of controversy has been the use of statistical flood models to determine the magnitude of flood associated with a specified recurrence interval (usually 100 years). Each of the half dozen or so major flood frequency theories (and the models based on them) produces somewhat different results in a given setting, even when the same data set is used for all cases. In some instances the different theories give considerably different results, so that estimates of the size of a 100-year flood, for instance, may vary by a factor of two or more. With that large a variation in flood magnitude, there is an attendant, but usually somewhat smaller, variation in flood hazard area—since the amount of land subject to development restrictions varies with the estimate of the 100-year flood magnitude. Flood frequency estimates at different points on the same stream using different models (or even at the same point using different models) often produce different results, causing a tremendous amount of confusion and controversy. Since the differences are not due to error in calculation, but to fundamental differences in the assumptions of the models, the differences are essentially irreconcilable. The need for consistency was a major factor in the Water Resources Council's decision to recommend a uniform technique (or model) for use by Federal agencies in performing flood frequency analyses. That decision has eliminated some, but not all, of the controversy.

Low-Flow and Drought Forecasting

Low streamflow is caused primarily by physical phenomena, while droughts result from the joint occurrence of low streamflow and high demand—a condition due to social and economic causes as well as physical ones. Modeling capability for forecasting and managing low streamflow per se is as highly developed as for flood forecasting. However, from the point of view of drought management, which requires an ability to modify both water availability and water use, the available models are less satisfactory.

The major difficulty in forecasting low flows stems from problems in choosing appropriate statistical procedures for determining how often to expect low flows of a specified volume and duration. Most of the theories used in hydrologic probability analysis are based on the concept of independence—the idea that two or more "events" are totally unrelated to one another. In the case of low streamflow, analysts are normally concerned with the quantity of streamflow during a specific period of time. Frequently, however, the specified period is part of a more extended period of low flow produced by general climatological and meteorological trends. For this reason, it is difficult to ascribe probability estimates to low-flow "events."

Perhaps because of the difficulty of determining low-flow probabilities, a common practice in planning and designing facilities for low-flow management has been to design for the "drought of record," i.e., the most severe low-flow period experienced in recorded history in a given watershed. Because of natural variation and differences in the length of available hydrologic records in different watersheds, the "drought of record" in some watersheds is very severe—perhaps with an estimated recurrence interval of 300 years or more—while in other watersheds the drought of record may have a recurrence interval of 20 years or less.

When the drought of record is used as a design standard, some facilities are inevitably underdesigned and others are overdesigned. Thus, while failures of flood control structures are rare, serious inaccuracies in low-flow management facilities are relatively common. Although alternative methods have been developed for calculating streamflow sequences of long duration based on statistical analysis of relatively short historical hydrologic records, planners have been reluctant to accept designs based on statistical methods that differ substantially from designs based on the "drought of record." Considerably more work is needed on the use of statistical methods for planning, designing, operating, and managing low-flow control facilities.

Public policy for dealing with low-flow problems has focused more on water availability policy than on water use in low-flow periods—except with regard to competition among uses (irrigation, hydroelectric power, municipal water supply), which will be discussed in the following subsection on streamflow regulation. Little use has been made of models for regulatory aspects of low-flow management, except where interstate compacts or judicial decisions have forced governmental entities to apportion low flow among competing users. In general, available models seem to be adequate for these needs.

Streamflow Regulation

The Nation has invested billions of dollars in facilities to regulate streamflow for a variety of purposes: to reduce flood damage; to generate hydroelectric power; to provide stable navigation channels; to provide dependable surface water supplies for municipal, industrial, and agricultural uses; to improve fish and wildlife habitat; and to provide recreational opportunities. Federal agencies alone have constructed hundreds of structures that regulate streamflow for one or more of these purposes. Thousands more have been constructed by other governmental entities, private enterprises, and individuals. Most of these facilities are passive; i.e., they require little, if any, operational management (other than routine maintenance) to accomplish their intended purpose. Levees, ungated diversion structures, and small dams with ungated spillways are typical facilities that require minimal operational management.

Hundreds of these existing facilities, however, are not passive. They are large, complex structures serving many purposes and requiring intricate daily, hourly, or sometimes even minute-to-minute operational management to achieve their intended purposes. Myriad conditions, criteria, and data must be identified and evaluated each time an operational decision is made. Some operational criteria are based on fixed conditions (e.g., those that ensure the safety of the structure) while others are based on changing phenomena (e.g., current and future weather conditions). Operational management is further complicated in multipurpose projects because some purposes are competitive (a decision favoring one purpose has an adverse effect on some other purpose), while others are complementary (a decision favoring one purpose has beneficial effects on other purposes). Operational management problems are even more complex in watersheds where two or more multipurpose projects exist. In this case, decisions for each project must be coordinated so that the projects themselves function in a complementary fashion.

Over the past decade, computer models that give the project manager much greater flexibility than previously used fixed operating rules have been developed. Thus, it is now feasible to model the operation of single projects or large systems of interconnected projects.

Many fixed operational rules have been replaced by models that permit day-to-day decisionmaking that can more effectively consider several objectives of a project (or projects) simultaneously. Most of the current models include only hydrologic inputs and outputs, and the physical operation of a project or system. Economic, social, institutional, and environmental factors affecting operational management are only considered indirectly, or evaluated outside the model. Despite their limitations, these models have the capacity to improve both short- and long-term operational management decisions and plans.

More recently, modeling capabilities for operational management of streamflow regulation structures have expanded to include mathematical optimization models and—in a few instances—online, real-time models used for controlling major portions of a system's operation. Some simulation models have also been expanded to analyze economic, institutional, and environmental factors. However, data acquisition (particularly for real-time operation) and model calibration are substantial obstacles to widespread use of the models currently available for large systems; many operating entities do not have sufficient computer capabilities and personnel to use the most sophisticated models available for onsite operational decisions.

Instream Needs

Determining instream flow needs differs from other water availability problems in that instream flow needs are frequently linked to water quality rather than water quantity requirements. The two most common purposes for establishing instream flow requirements are to preserve and protect aquatic and riparian ecosystems, and to comply with statutory, contractual, or institutional obligations to maintain the necessary streamflows.

The common practice of specifying instream needs in terms of water volume dates back to the earliest days of water resource development in this country, when allocating water to meet these needs was labeled "low-flow augmentation." While it was recognized that many of the objectives of low-flow augmentation were related to water quality characteristics rather than to water quantity per se, virtually all of the analytic techniques available for planning and managing streamflow regulation were quantity oriented.

In the mid-1960's, knowledge of water quantity/water quality relationships and computer modeling capabilities simultaneously reached the point where it became possible to model many important water quality characteristics in reservoirs and streams. The first such models dealt with the two best understood quality characteristics—temperature and dissolved oxygen. These two characteristics were considered to be particularly important because they are involved in virtually all physical, chemical and biological processes occurring in streams.

By the early 1970's existing models were capable of assisting planning efforts to meet instream needs based on water quantity requirements, and providing information for some policy and regulatory aspects of instream-needs analysis. However, the available models could not, in most cases, produce results commensurate with requirements for operational management. New models that show promise for meeting the requirements for management decisions have recently begun to appear.

The role of models in policy and regulation of instream flow is limited by a lack of knowledge about the qualities of instream flow required to ensure the survival of fish, wildlife, and other aquatic and riparian biota. Many existing instream requirements are based on extremely limited information concerning biological survival and tolerances. Most existing standards establish a single value for instream needs, so that in essence a pass-fail condition exists. In policy and regulatory work, tradeoffs are critical components of analysis, and tradeoff analysis is severely hampered when degrees of success and failure cannot be analyzed. Improved understanding of relationships between instream flow and biotic life would greatly enhance the utility of existing models in policy and regulatory areas.

Water Use Issues

Domestic Water Supply

Domestic water suppliers in this country usually assume a utility responsibility—i.e., that of a regulated monopoly—in their service area. In effect, they agree to provide services to all users within the service area according to an established rate structure, and to assure, insofar as possible, that the service is equally available and dependable for all users. This does not preclude the possibility of establishing service classes or priorities for various categories of users (e.g., differentiating between purely domestic use and industrial use), but such practices are much less common in the water supply industry than in the electric power industry. Because of this "utility" philosophy, water agencies have traditionally worked much harder to secure additional supplies than to control or manage demands.

In many instances, domestic water use projections have consisted solely of projecting changes in population and applying established per capita demand factors to the projected future population. In some cases projections have been somewhat more sophisticated. Some analysts recognize that per capita consumption is affected by changes in demography, technology, and lifestyles, and attempt to adjust current per capita consumption estimates to reflect anticipated changes in these factors. However, only a modest amount of data is available on which to base such adjustments.

As growth in domestic demands and competing uses diminish the relative availability of water, water utilities will have to develop and evaluate alternatives for obtaining additional supplies, or strategies for allocating available supplies among competing users. Models can be used to establish pricing policies, user priorities, and other economic and technological aspects of system expansion. Models can also play a useful role in examining the likely responses of various sectors (domestic, commercial, municipal, and industrial) to strategies that might be used to achieve targetted reductions in use.

If priority use and pricing systems come into widespread use, models will be needed to assist in determining the conditions under which use priorities should be implemented, and the amounts of water that should be made available to each user class.

When additional supply capacity is deemed necessary, models can be used for planning efforts to develop and expand water distribution systems. These models focus primarily on the hydraulics and economics of the distribution system itself rather than on water use characteristics.

Irrigated Agriculture

Model use in the area of irrigated agriculture has a relatively long history, and has grown more rapidly and is more widespread than for other water uses. Since irrigation occurs primarily where rainfall is deficient, farmers have had to be more conscious of the importance of water and of the need to manage a limited supply. Uses of models have ranged from determining the need for irrigation water and timing applications for specific crops, to developing policies for allocating water among users in times of water shortage. Models are also used to plan, design, and operate water distribution systems for large irrigation projects.

Some of the models available for planning and operational management of irrigation water are extremely sophisticated. They enable users to consider water requirements of individual crops over an entire growing season or for specific intervals within the growing season. The models can also gage the effect of precipitation on the amount and timing of needed irrigation water. Some of the most sophisticated models permit users to consider options to defer applying water or to reduce the amounts of water applied during periods of water shortage. These models provide information on the risks of crop failure or the likelihood of reduced crop yields, thereby helping farmers to apportion limited supplies among various crops. Such models also provide information on the economic consequences of buying and selling water entitlements.

The availability of these models to farmers involved in irrigated agriculture will be even more important in the future, as competition between irrigation and other nonagricultural water uses increases in the Western States.

Other Offstream Uses

Water is also used for such purposes as cooling in thermal electric power-generating plants; process water and cooling in coal gasification, shale oil production and other energy extraction and conversion processes; hydraulic mining; and for use as a transport medium in slurry pipelines. Many of these uses require withdrawals of large quantities of water from rivers and streams. In some cases (e.g., evaporative cooling, slurry pipelines, and interbasin transfer) not only are the withdrawals large, but the use is "consumptive"—i.e., the water withdrawn is lost from the stream system from which it was withdrawn. In other cases (e.g., once-through cooling, mineral extraction, and energy conversion), while withdrawals are relatively large, the use is not consumptive because the water eventually returns to the stream after use. In some of these cases, however, the quality of the returned water is substantially altered and the water may not be fit for many other uses.

Models are currently available to assess the effects of offstream uses on water quantity and to assess such common water quality characteristics as temperature and dissolved oxygen changes. However, improvements in models are needed for assessing the economic and environmental implications of water withdrawals and potential water quality changes due to offstream uses.

Policy and regulatory functions are greatly affected by the lack of adequate modeling capability in this problem area. The volume of some proposed offstream uses—e.g., coal gasification or liquefaction and oil shale processing—is so large that decisions regarding them are likely to affect the economies and ecologies of large regions and involve a considerable number of governmental jurisdictions. Information from models would be of great value in resolving the controversies and inter-jurisdictional disputes that will inevitably arise.

Efficiency and Conservation

Models for dealing with water use efficiency and conservation are considerably different from models used in other aspects of water management. With the exception of irrigated agriculture, water users in this country have not emphasized efficiency and conservation except during periods of critical water shortages. Consequently, there is no substantial body of knowledge regarding efficiency and conservation strategies and their economic, social, and environmental consequences. Some data exist on specific conservation practices and their effects in isolated pilot programs under "normal" conditions, and some data exist on a wide range of conservation practices and effects under emergency conditions. However, it is doubtful that the existing data base and knowledge (other than for irrigated agriculture) provides a sufficient basis for developing the models needed for policy and planning functions.

Pertinent economic models—e.g., models to determine the effects of water pricing on use—are discussed in "Social and Economic Models" of this chapter.

Evaluation of Currently Available Surface Water Flow and Supply Models

Table 7 presents evaluations of currently available surface water flow and supply models. Each water resource issue is subdivided into specific model applications; for example, under the issue of "flood forecasting and control," the capabilities of models vary for the seven applications addressed. Models are rated from A to F, with A indicating that modeling for this purpose does a good job in supplying the needed information, and F indicating that the state of the modeling art for this purpose is generally unsatisfactory.

Table 7.—Surface Water Flow and Supply Model Evaluation

Issue	Information required for applications	Overall rating
Water availability:		
1. Flood forecasting and control	a. Flood peaks for channel and bridge design	B
	b. Flood hydrographs for reservoir design and operation	C
	c. Simultaneous flood hydrographs for flood control system design and operation	C
	d. Flood depth mapping for flood plain land-use planning	C
	e. Effects of land use on downstream flows for upstream land-use planning	C
	f. Flood peaks after dam failures for emergency preparedness planning	D
	g. Soil moisture conditions for land drainage design	C
2. Drought and low-flow river forecasting	a. Low river flows for offstream uses	C
	b. Timing of drought sequences for estimating cumulative economic impact	B
	c. Soil moisture conditions for precipitation-supplied uses	C
3. Streamflow regulation (including reservoirs)	a. Runoff volume for maximum obtainable yield	A
	b. Runoff time patterns (within and among years) for reservoir sizing	B
	c. Simultaneous runoff volumes in regional streams for regional water supply planning	C
4. Instream flow needs:		
Fish and Wildlife	a. Low river flows for estimating fish support potential	C
	b. Within-year timing of low flows for fish lifecycle matching	B
	c. Timing of drought sequences for estimating minimum reservoir or lake levels	B
	d. Flow velocities within streams for estimating effects on fish species	C
Recreation	a. Low river flows for sustaining recreation capacity and esthetic appeal	C
	b. Timing of flow sequences for matching with recreation periods	B
	c. Runoff time patterns (within and among years) for estimating the impact of fluctuations in lake levels	B
Navigation	a. Low river flows for determining waterway capacity	C
	b. High river flows for determining navigation interference	C
	c. Formation of surface ice for determining navigation interference	D
Hydroelectricity	a. Timing of flow sequences for estimating run-of-the-river generating capacity	B
	b. Runoff time patterns (within and among years) for designing streamflow regulations	B
	c. Simultaneous runoff volumes in regional streams for regional generating system planning	C
Water use:		
5. Domestic water supply	a. Timing of water use for delivery system design	D
	b. Water pressures throughout delivery system for delivery system design	C
	c. Volume of use for sizing supply facilities	B
	d. Return flow volumes for designing wastewater collection systems	C
6. Irrigated agriculture	a. Timing of water use for delivery system design	C
	b. Volume of use for sizing supply facilities	B
	c. Return flow volumes for drainage system design	B
7. Other offstream uses	a. Volume of industrial use for sizing supply facilities	B
8. Water use efficiency	a. Effect of increased use-efficiency on return flows for evaluating conservation measures	C

Rating Key:
A Modeling of the physical process at the current state-of-the-art does a good job in supplying the needed information.
B Information between adequate and good.
C Modeling does an adequate job for most purposes.
D Information between unsatisfactory and adequate.
F The supplied information is generally unsatisfactory.

SOURCE: Office of Technology Assessment.

SURFACE WATER QUALITY

Introduction

Billions of dollars are spent annually in the United States to protect the quality of surface waters. Unless carefully managed, residual wastes from municipalities, industry, and agriculture can seriously interfere with many beneficial water resource uses. Water quality models are used extensively in Federal, State, and local efforts to maintain and improve the quality of the Nation's surface waters.

Water quality models serve two general functions. The first is to provide basic scientific insight and understanding about the relationships between material inputs and water quality changes. These relationships are expressed in the form of mathematical equations that interrelate and synthesize observations. The second function is of an engineering nature. Once confidence in these relationships is obtained, the equations can be used to help manage, plan, and make policy. Given the present state of scientific knowledge and engineering development, existing models can generally provide a limited basis for water quality decisionmaking.

Mathematical models of water quality are most frequently used for planning, to some extent for policymaking, and to a lesser degree for day-to-day operations and management. Their most common use is to determine the degree of treatment required for a specific wastewater discharge in order to achieve or maintain a desired receiving water quality. Other uses include determining the magnitude and effects of urban runoff, and assessing the effectiveness of alternative measures for preventing soil erosion and the resulting sedimentation within water bodies.

Because models simply quantify existing scientific knowledge about water quality, a basic understanding of the processes that underlie model equations and assumptions is helpful in assessing model capabilities. The next section, "Types of Models Used in Surface Water Quality Analysis," describes the current state of scientific knowledge about determinants of water quality, and examines how well this knowledge is incorporated into present water quality models. Later, the state of the art of water quality modeling is discussed on an issue-by-issue basis, analyzing 10 major problems under the general categories of point and nonpoint pollution sources. The section entitled "Evaluation of Currently Available Surface Water Quality Models" assesses currently available model types. Evaluations are made both according to the characteristics of the models themselves, and for the 10 major problems to which they may be applied.

When considering water quality concerns, four basic questions face the analyst:

1. What is the *quantity and quality* of the water and residuals coming from each point and nonpoint source?
2. How are these materials transported *to* the receiving waters?
3. How are these wastes transported *within* the receiving water?
4. What processes *transform* waste residuals within a water body?

Given the response of the system, the analyst must further consider the following questions:

- What deleterious effects do these wastes have on beneficial uses?
- Do existing standards reflect the magnitude of the effects?
- What control alternatives are available, how well do they perform, and how much do they cost?
- Are these control alternatives politically, economically, and esthetically feasible?

All of the above information is needed for management, planning, and policy decisions. Models are available, in varying degrees of detail and accuracy, to help the analyst address each of these questions.

The common basis for the majority of water quality models is the principle of "mass balance." Water and any material inputs from natural or human sources are followed: 1) from their point of origin; 2) as they travel to the water body; and 3) as they travel within the water body. The models account for biological, physical, and biochemical reactions that occur, and additions of water or materials.

To run these models, users must provide quantitative estimates of the characteristics of the watershed and the receiving water body. Source quantities, constituents, and other pertinent characteristics must be enumerated, and the numerical coefficients that describe the above reactions must be known.

Water quality models have one aspect that is both a vice and a virtue—most provide an absolute numerical value for any given variable such as the concentration of a pollutant. While it is desirable to have such a number, often no indication of the possible error is given. In practice, most water quality projections are subject to large errors and must be validated with field observations.

However, water quality models are still very useful in planning contexts, for example, because *relative* effects of control alternatives can be analyzed with sufficient confidence for many purposes. Model projections, when combined with the professional judgment of water resource analysts, are often the best information available to aid the decisionmaker in evaluating alternatives.

Types of Models Used in Surface Water Quality Analysis

All water bodies are affected by inputs from natural sources and human activities. The accuracy with which models can estimate relationships between these inputs and the water quality response determines their utility for management, planning, and policy purposes. Thus, current levels of scientific and engineering knowledge about these relationships form the basis for assessing surface water quality models.

Water quality models can be divided into three components that describe:

- source of materials;
- transport to and within the receiving water; and
- processes occurring within the receiving water;

The first component estimates the inputs of substances through human activities and natural phenomena; the second, the hydrologic and hydrodynamic regime of the water body and its watershed; and the last, the biological, chemical, and physical processes that affect water quality.

Source of Materials

Water bodies may receive point source discharges from municipal, industrial, and agricultural activities; dispersed or nonpoint source runoff from these same areas; natural inputs from undisturbed watersheds; and additional chemicals from rainfall.

The chemical characteristics of effluents from municipal sources are well known with respect to both average values and their variations. This is also true for many industries that generally produce one or a few products, such as the pulp and paper, canning, and steel industries. However, industries that produce a variety of products, such as organics, synthetic chemicals, and pharmaceuticals, produce discharges that are more difficult to characterize.

Information on agricultural and feedlot sources of waste is meager, but has been improving in recent years. Irrigation return waters pose difficult problems, particularly in the mid- and far-western regions of the country where high background concentrations of salts of natural origin prevail. The time-variable nature of return flows, which are both point and distributed, introduces additional complexities. Our social and scientific awareness of these problems is relatively recent; consequently, the historical data on these sources are minimal, and many gaps remain in current knowledge of the governing phenomena.

The ability to quantify pollutant loadings from a variety of sources is critical, particularly with respect to differentiating between point sources, which are readily controllable, and nonpoint sources, which are relatively difficult to identify and control. Assigning realistic values to distributed nonpoint sources is very difficult, given the present state of knowledge and data. Current models provide at least some assessment of the problem.

The most significant information gap lies in quantifying toxic substances from nonpoint sources or from residues of toxic materials created by past activities, e.g., from riverbeds and from landfills that leach into water systems.

Transport to and Within Receiving Waters

Point discharges are transported by pipes, open channels, or other conveyance devices from the point of origin to the receiving water on a regular basis. Nonpoint discharges move through storm drainage systems, via overland flow, and through subsurface flow to the receiving water as a result of rain events. Consequently, the quantities of materials entering water bodies from nonpoint sources are much more difficult to predict.

Most surface water quality models include a surface water flow submodel as part of the program, since in most cases it is necessary to predict runoff and flow quantities before making quality estimates. Many of the models discussed in the previous section on surface water flow are used as components of surface water quality models.

Pollutant transport by rivers and streams is, in general, better understood than transport within lakes. Transport in streams depends primarily on flowing water; within lakes, and some complex river systems, movement of pollutants occurs by diffusion and dispersion as well—difficult processes to model. In addition, a longer and more extensive data base is available for streams than for lakes.

Transport in streams can be approximated by simple one-dimensional models—the one dimension being the direction of flow. Under certain conditions, simple models can adequately simulate transport in lakes, but often more complex two- and three-dimensional models are necessary. The state of knowledge and computational techniques are such that only the most proficient analysts can use these models.

The above remarks apply to situations that are not highly time dependent. When water quality analysis must incorporate such factors as storm surges from combined sewers or rapidly changing river flows, the models must be considerably more complex. These models are still in the developmental stage and their results are only marginally useful at present.

Processes Occurring Within the Receiving Water

In general, the chemical, physical, and biological processes of rivers and streams are better modeled than those of lakes. In addition, more extensive water quality data exist for rivers and streams, particularly for such constituents as dissolved oxygen and coliforms (bacteria used to indicate the presence of sewage).

Eutrophication (excess algae or aquatic weed growth) is another widespread problem. The nutrients that cause eutrophication originate from a variety of municipal, industrial, agricultural, and natural sources. While the state of the art permits some model-based assessment, data requirements are so extensive that these techniques are often impractical. Simplified approaches, involving the nutrients phosphorus and nitrogen, presently yield results that may be indicative and, in certain cases, adequate for the intended purpose.

For inorganic and organic chemical water quality, the present state of knowledge is mixed. The biochemical reactions of certain industrial chemicals are sufficiently understood to permit the development of reliable models. This is true for a wide range of chemical compounds of relatively simple structure, which are commonly present in industrial effluents and which are susceptible to the presently available treatment processes. While the reactions involving metals are not as well understood as those of the simple industrial chemicals, they have been developed to a degree that will permit at least a marginal analysis and projection.

On the other hand, for more complex compounds, many of synthetic composition, far less is known about reactions, byproducts, and removal by present treatment techniques. These substances, which include many toxic materials, may be modeled with simplifying assumptions, yielding reasonable projections in limited cases. However, on the whole, current methods of analysis are regarded as only marginally reliable. A similar assessment applies to complex metals when concentrations approach or exceed toxic limits. Water quality models that analyze these substances are presently being developed.

A second area of notable uncertainty is the accumulation of toxicants in the food chain leading to fish. Much research has been undertaken over the past decade to advance basic understanding of the problem, collect data, and develop models, some of which appear to be very promising. Preliminary

Photo credits: © Ted Spiegel, 1982

Researchers are exploring natural capabilities to reduce nutrient levels in effluent flows as a potential means of tertiary sewage treatment. At left, water in a meandering stream is cleansed through contact with vegetation and reaerated on its way to the Hudson River; at right, a Florida cypress dome is fertilized with the nutrients in partially treated effluents from a 150-unit mobile home park. Models are available to estimate the effectiveness of various treatment methods in removing such nutrients as phosphorus and nitrogen, and to assess the effects of nutrients on biological processes in lakes and streams

food chain and fisheries models are available; however, these are in a relatively primitive state. Although they may provide some insight and understanding, they are neither sufficiently calibrated nor adequately validated for management purposes.

The same may be said for aquatic ecosystem models that describe changes to aquatic plant and animal populations subjected to water quality stresses. Ecosystem theory—the basis for such models—is still in a developmental stage. However, the results of laboratory studies on the effects of specific pollutants on sensitive organisms have been incorporated into water quality models with some success.

Nonpoint Source Issues

Urban Runoff

Urban runoff (along with agricultural runoff) is one of the most difficult waste discharges to control because of its intermittent nature and varying quality. Federally mandated control and management of urban runoff has created the potential for increased use of urban runoff models.

At present, urban runoff models are most helpful in planning, primarily for water quality management and comprehensive areawide planning. The best examples lie in the section 208 programs of the Clean Water Act—particularly the Nationwide

Urban Runoff Program. Such planning is designed to provide each State and the Environmental Protection Agency (EPA) with information on point source and nonpoint (including urban runoff) treatment needs and the effectiveness of treatment methods. Urban runoff models such as EPA's Stormwater Management Model and the Corps of Engineers' STORM can simulate the quantity and quality of runoff from a specified runoff area and can be used to compare the effectiveness of alternative control strategies. These models may also be linked to receiving water models to gage the effects of urban runoff on receiving water quality.

Urban runoff models can also play an important role in Federal and State agency policy decisions. Federal agency construction grants allocations, and requests for such funds by State agencies, could be based in part on estimates of the volume and quality of point source and nonpoint source wastes in a specific area, the effects of these wastes on the receiving water, and the effectiveness of nonpoint source control in alleviating the problem.

Urban runoff models do not appear to have attained the credibility necessary to be used as regulatory tools at this time. These models require an extensive local data base, and such information is usually unavailable, except for cities in which specific studies have been performed to develop, calibrate, and test such models.

Erosion and Sedimentation

Models of erosion and sedimentation are developed primarily by such Federal agencies as the Corps of Engineers, the Soil Conservation Service, the U.S. Geological Survey, and, to a lesser extent,

Photo credit: U.S. Department of Agriculture

Two years of low rainfall on the Big Canyon Ranch near Sanderson, Tex., greatly reduced plant cover levels, setting the stage for extremely high runoff rates on the draw pictured above after rainstorms hit an area 30 miles away. Plant cover is a major determinant of soils' abilities to absorb moisture and resist erosion; runoff and erosion models consider cover levels as one of many factors in estimating flows and sediment transport

EPA. Extensive use is made of erosion and sedimentation models by Federal, State, and local agencies concerned with river management. Construction agencies use these models to assist in operational management, e.g., in dredging navigation channels and operating reservoirs. Sedimentation is a critical factor in reservoir management, as it can reduce a reservoir's useful volume. River authorities must have information on rates of sedimentation and ways of alleviating or minimizing sedimentation to operate their reservoirs most efficiently.

Local, State, and Federal agencies concerned with forestlands, rangelands, and farmland management continually seek better ways to minimize soil erosion. They employ models to guide the selection of effective management techniques.

A primary concern is the large amounts of nutrients (especially nitrogen and phosphorus) contained in eroded soils. Soils reaching waterways may impart those nutrients to the water, potentially causing nuisance algal growths or other symptoms of eutrophication.

Probably the greatest utility of erosion and sedimentation models lies in the area of planning. For example, the Corps of Engineers employs such models to plan and design erosion control structures along rivers and coastal areas and to estimate the extent of sediment accumulation over the life of a reservoir. The Soil Conservation Service uses erosion models to plan erosion control programs on farmlands and forestlands.

Because toxic chemicals often adhere to river sediments, sediment transport models are used to predict the movement and fate of toxicants accidentally released into waterways. EPA relies on water quality models incorporating sediment transport submodels to follow the transport of Kepone down the James River to the Chesapeake Bay. The agency is using this information to plan monitoring programs and subsequent mitigation programs, if needed.

Salinity

Several factors may cause the buildup of excess salinity in surface waters. One major source is irrigation return flows. To maintain a favorable salt balance in agricultural soils, farmers may apply more water to their crops than is required for plant production. The additional water leaches out excess soil salts that may either flow overland to surface waters or percolate to the ground water. The erosion of soils with high salt contents, such as the marine shales found extensively in the West, and the input of salts from natural sources, such as brines, also contribute to excess salinity. Finally, the concentration of salt in surface waters can increase due to evaporation, reductions or diversions in flow, and plant transpiration.

Salinity, as a physical process, is one of the best understood pollution problems, and relatively easy to model. Many models exist to predict salt concentrations in agricultural drainage as a function of crop, soil type, and irrigation practice; downstream salinity concentrations; and the effects of excess salinity on crops, metal deterioration, soap consumption, and health. A well-developed data base complements these models.

Models are widely used to develop management strategies for salinity control. They can provide managers with information on the effectiveness of control options for reducing downstream salt concentrations. In addition, these models are useful for evaluating the likely effects of proposed regulations. From a planning standpoint, these same models are used to develop areawide salinity control plans and can aid in setting funding priorities to implement these plans.

In the ares of policy, salinity is an important aspect of international water rights issues and treaty obligations between the United States and Mexico. In particular, the salinity of the Colorado River has been a major international issue for some years. The increase in salinity of the Colorado from saline return flows before it leaves the United States is a major problem for water users in Mexico. Models have been used to determine whether planned consumptive uses from the Colorado Basin will allow the United States to meet its treaty obligations for delivering water at or below a specified salinity.

Agricultural Pollutants

Agricultural pollutants are found in runoff from irrigated and nonirrigated agricultural lands and pastures. The pollutants include soil particles eroded from the land; organic substances from decaying vegetation, animals, and feedlot waste; nitrogen and phosphorus from commercially produced fertilizers as well as from animal waste; and pesticides that have been applied but are not yet degraded. These pollutants find their way into nearby receiving streams, where their effects must be assessed.

Agricultural pollutants are generally considered to originate from nonpoint sources; animal feed lots, however, are considered point sources. Like other point sources, the latter must be treated to meet effluent and receiving water standards according to sections 301 and 303 of the Clean Water Act. Nonpoint sources are eventually to be controlled as well, but standards and guidelines for implementing controls have not yet been promulgated.

Mathematical models aid in assessing the instream effects of these point and nonpoint sources —such analyses play an important role in regulating pollution sources. The models for tracking organic materials and their effects on oxygen resources in streams are well developed, well documented, and easily usable by personnel with appropriate analytical skills and knowledge of water quality management principles. Such models should also withstand the scrutiny of litigation. Models for nutrients and pesticides, however, are not used as broadly as models that predict levels of dissolved oxygen.

Mathematical modeling of agricultural pollutants finds extensive use in planning. Models have been used primarily for section 208 studies of areawide pollutant problems and water treatment needs. Such studies enable States and EPA to establish priorities for treatment, based on estimates of the effects of point and nonpoint sources on receiving waters.

Not only do Federal and State agencies use mathematical models for the kind of planning mentioned above, but they also use these models to determine the effectiveness of treating agricultural pollutants, recommend funding levels to Congress, and propose legislation for controlling agricultural pollutants. In these cases, mathematical models may be the only means of linking the pollution source to effects on the receiving waters—a connection that is important in estimating the benefits of regulatory programs.

Photo credit: © Ted Spiegel, 1982

Agriculture can also serve as a means of treating certain water pollutants. Lubbock, Tex., utilizes a 3,000-acre farm as its tertiary disposal facility, employing nutrient-laden waters to irrigate and fertilize crops

Airborne Pollutants

Since the enactment of the 1971 Clean Air Act, mathematical models have been used as regulatory tools by Federal and State agencies that are assigned responsibility for air pollution enforcement. Such models determine the relationship between discharge and downwind exposure concentrations of common air pollutants such as sulfur oxides, nitrogen oxides, and particulates. Some of these pollutants are transferred from the air medium to water and thus contribute to water pollution. Such materials include windblown dust, hazardous substances, and compounds that may eventually produce acid precipitation.

The transfer of pollutants from air to water has received increasing attention in the last few years.

Hazardous substances in incinerator effluents and windblown erosion from landfill sites are problems for which mathematical models may be used to anticipate and formulate control strategies. Models of short-range pollution transport (less than 200 km) are currently available. The potential consequences of acid precipitation, and of the deposition of heavy metals, radioactivity and other hazardous materials from powerplant air emissions, may require Federal and State agencies to assess future water quality problems resulting from increased energy production. Models of long-distance pollution transport, and of atmospheric processes that may produce acid rain, are in early stages of development.

Point Source and General Issues

Wasteload Allocation (Point Source)

Wasteload allocation refers to the process of determining the amount of some waste material that a particular discharger is allowed to release by analyzing the relationship between discharged amounts and resulting concentrations in the receiving water. This cause-effect relationship may be determined after the fact through sampling programs, or before discharges occur with the help of mathematical models.

Water quality models find their most appropriate regulatory roles in estimating waste treatment needs for compliance with the Clean Water Act. The act sets forth two criteria for water quality standards: 1) effluent requirements for regulating "end-of-pipe" discharges, as specified in section 301 of the act; and 2) receiving water standards, as specified in section 303 of the act. Discharges who meet effluent standards may be required to provide further treatment if resulting waste discharges cause higher-than-acceptable receiving water concentrations. Wasteload allocation models determine the maximum allowable level of discharge for individual producers in order for pollutant concentration levels in receiving waters to be at or below existing standards. Removal techniques to meet these limits can then be selected.

Mathematical models for this procedure are well developed and documented, can be adapted to receiving waters of different types, can be easily used by regulatory staff, and are reliable enough to withstand judicial scrutiny. Waste allocation is particularly complex, however, when a number of discharges reach a common receiving water near the same point. In such cases, the allowable wasteload can again be determined by a mathematical model, but assigning wasteloads equitably among the contributors must be a legal and administrative decision.

Water quality models have been used extensively in planning for treatment needs throughout the Nation. As part of section 208 of the Clean Water Act, point and nonpoint wasteloads were to be determined for segments of the Nation's waterways. Mathematical models were used in these cases, first to estimate current loadings from the point and nonpoint sources, and then to estimate the impact of these loadings on the receiving stream. Based on the magnitude of these effects, the need for wasteload reduction was determined. Then, based on the ratio of point source to nonpoint source discharges, Federal and State agencies could estimate where the greatest water quality improvement could be achieved at the least cost.

Probably the most dramatic and exemplary policy-level application of these water resource models was undertaken by the National Commission on Water Quality. The commission, mandated by Congress as part of the 1972 Federal Water Pollution Control Act Amendments (Public Law 92-500), undertook a number of assessments of the social, economic, technical, and environmental impacts of implementing the other sections of the act. Among the commission's responsibilities were a set of water quality studies to evaluate the act's impact on some 40 specific areas around the United States. Water quality models were used extensively in these studies and were, in fact, necessary to carry them out. Study results indicated that the effluent regulations of the 1972 act should be altered to reflect more realistically attainable levels of treatment in the allotted time periods. The work of the commission contributed to policy changes within EPA, and influenced congressional formulation and passage of the 1977 Clean Water Act (Public Law 95-217), which incorporated many of the commission's recommendations.

Wasteload allocation models were critical to the commission's ability to demonstrate the consequences for the Nation's receiving water quality of

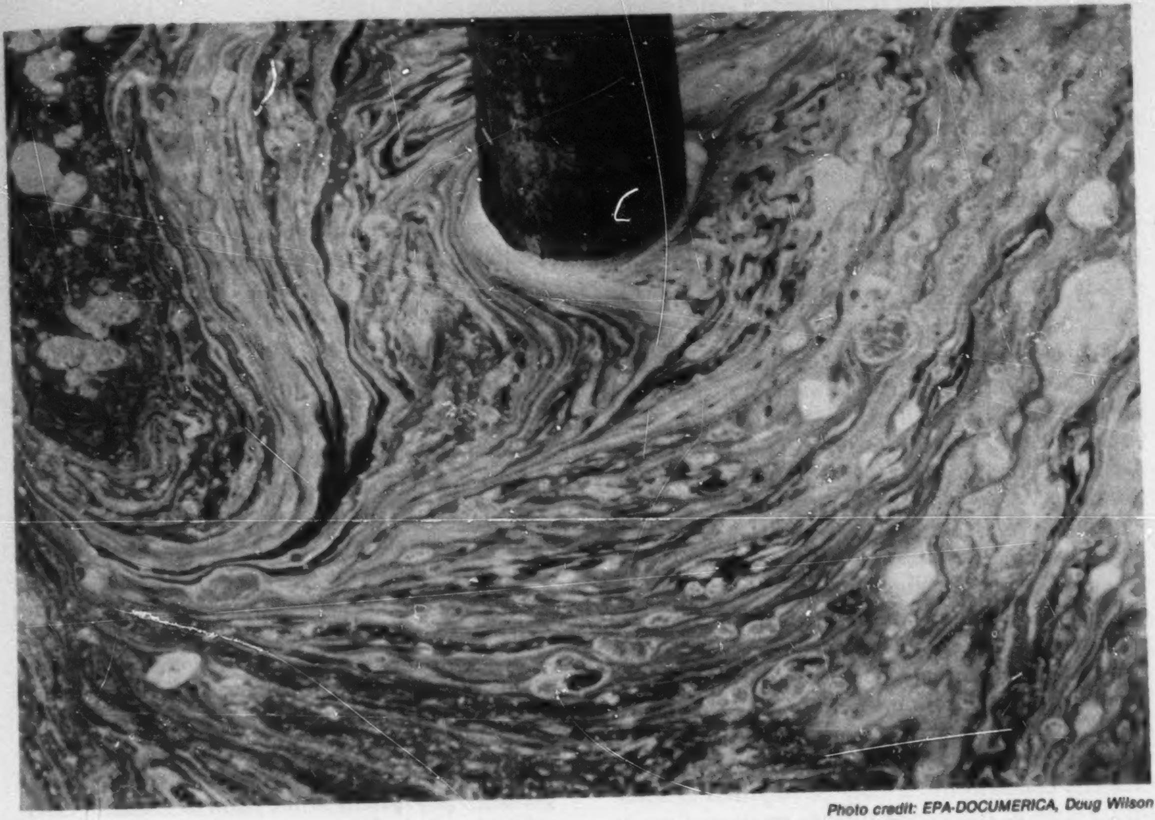

Photo credit: EPA-DOCUMERICA, Doug Wilson

Untreated water from a pulpmill in Puget Sound, Wash.

implementing the 1972 act. The study also revealed some shortcomings in then-current modeling capabilities, however. Contractors performing work for the commission relied primarily on dissolved solids and dissolved oxygen models; models for nutrients and toxic materials were applied in only a few situations, largely because existing data bases were inadequate for calibrating and validating them.

Thermal Pollution

Thermal effluents are among those regulated by the Clean Water Act. Effluent limits have been set for thermal wastes as well as for allowable temperature increases in receiving waters. Zones of influence and resulting temperature increases from thermal effluents can either be monitored directly or predicted with mathematical models.

Mathematical models for thermal wastes range from fairly simple one-dimensional models to more complex two- and three-dimensional models. Most of these models have been developed through the support of EPA and the electric utility industry and have been applied in many locations. Most regulatory staffs can operate the simpler thermal waste models, but the more complex multidimensional models require well-trained staff.

The electric utility industry uses mathematical models extensively in applying for construction and operation permits for nuclear powerplants through the Nuclear Regulatory Commission, and in preparing environmental impact statements as required by the National Environmental Policy Act of 1969. Under the latter act, the permittee must show the extent of the environmental impact of its facility, in particular the impact of the thermal waste. Such effects are routinely forecasted by using mathematical models.

Toxic Materials

Compounds that cause some injury to humans or other organisms of concern are classified as toxic materials. Such materials are not necessarily lethal, but may be compounds that produce such sublethal effects as cancer, birth defects, or reproductive failure.

Toxic materials are regulated under several statutes, including the Clean Water Act, the Toxic Substances Control Act of 1976 (Public Law 94-469), the Resource Conservation and Recovery Act of 1976 (Public Law 94-580), and the Safe Drinking Water Act of 1974 (Public Law 93-523). Regulation under this last act is discussed in the section entitled "Ground Water Quantity and Quality." Although control is focused on technology-based standards, mathematical models have potential roles in enforcing portions of these acts. As with other pollutants, effluent requirements have been established for point sources based primarily on removal techniques. However, receiving water criteria must be met as well. Modeling for toxic material concentrations may be required at some future time to determine further treatment needs if receiving water standards are not being met.

While legislation exists for control of nonpoint source toxicants, implementation has been given low priority. As controls are applied, however, ground and surface water quality models could play an important role in determining the cost effectiveness of alternative control measures. Mathematical models can also be used to design monitoring networks so that stations can be best located and sampled to gain maximum information from monitoring.

As with other issues, mathematical models for toxic materials have greatest utility in the planning process. Models can be used to anticipate problems, and to test different management approaches for removal effectiveness and managerial efficiency. Since regulations for controlling liquid and gaseous sources of toxic substances are currently being implemented, and those for hazardous solid wastes have recently been issued, models for planning long-term toxic material control should find widespread application.

Drinking Water Supply

The Safe Drinking Water Act is the principal Federal legislation regulating the quality of drinking water. It, along with State statutes and local ordinances, regulates the quality of public drinking water. Regulations apply to water quality at the end of the treatment process; consequently, streamwater quality models have no roles per se in regulating drinking water under this act. However, toxicology models, which relate concentrations of various hazardous substances to human health risks, are used to aid in setting standards. These models use differing methods for extrapolating data from animals to humans, so that resulting estimates of human risk may diverge widely. The OTA report, *Technologies for Determining Cancer Risks From the Environment,* provides an assessment of toxicology models.

The quality of the raw water is an important factor in supplying high-quality water for human consumption. Where raw waters are degraded by upstream users, water quality models can be used to predict water quality at the point of intake to determine the level of treatment needed. In particular, water quality models are used in determining when intakes should be closed due to contaminants originating upstream. For example, a spill of carbon tetrachloride in the Ohio River several years ago forced water users downstream to close intake structures at appropriate times to avoid contaminating the water supply. Models were used to predict when and how long the carbon tetrachloride would be in the vicinity of the intake structures.

Water Quality Impacts on Aquatic Life

Models for predicting water quality impacts on aquatic life involve two steps: 1) estimating concentrations of those materials that may affect aquatic life (positively or negatively), and 2) comparing calculated concentrations with accepted criteria to judge the consequences of those concentrations to the ecosystem. This latter step is seldom incorporated into the model structure, and requires professional judgment by aquatic ecologists.

The models used to assess impacts can vary from very simple models for calculating the effects of concentrations of selected materials, to very complex models incorporating several different types of pollutants and their effects on numerous organisms. The complex models are the least reliable, due to the lack of data to support many of the necessary assumptions and the great difficulty in calibrating and validating them. Both types of models require considerable professional judgment in applying the results to field situations.

Models to determine water quality impacts on aquatic life are primarily of value in the planning process. This is due to the kinds of applications that can be made of these models, the current state of their development, and the number of areas for which data are adequate to apply them.

Aquatic life impact models can be usefully applied if a theoretical analysis of the aquatic system is coupled with coefficients derived from controlled laboratory experiments. Examples include models of the movement and effects of Kepone in the James River, of polychlorinated biphenyl (PCBs) in the Hudson River, and of PCBs in the Great Lakes. Both the Kepone and PCB models facilitate impact assessment by allowing researchers to compare exposure concentrations to tolerable levels, while the PCB models can predict alterations in populations if toxic interactions are included. These models have been used to forecast the effectiveness of alternative remedial actions, and thus help provide a basis for future regulatory activities.

Evaluation of Currently Available Surface Water Quality Models

A model's level of complexity and its degree of availability provide the basis for a simple scheme of classification. Accordingly, four generic types of models are outlined below, and their basic capabilities are summarized. In the evaluation table (table 8), these four generic model types are rated according to their utility in analyzing five major aspects of each of the 10 issue areas discussed above. The evaluation table also assigns an overall rating for modeling sophistication in each issue area. Using a potential scale of zero to 10, actual assigned ratings range between 1 and 9, indicating the uneven level of current modeling capability for surface water quality analysis.

Type I is a standardized procedure or technique that may be routinely performed without a computer. It involves simple mathematical equations, statistical techniques, and graphical procedures. Examples include use of the Streeter-Phelps stream model for evaluating dissolved oxygen downstream of point sources (although this is often programed into complex models), and evaluating lake eutrophication potential with diagrams or regression equations. While the procedure does not involve a computer, it is not necessarily unsophisticated. On the contrary, some "desktop" procedures are mathematically quite sophisticated, whereas some complex digital computer models are nothing more than a programed version of intuition. Finally, a Type I model may still require considerable time and effort and the use of computational aids (e.g., hand calculators) to be fully operational.

Type II is a computerized version of a Type I model. This may avoid the tedium of routine calculations and greatly expand the amount of data that can be processed. The level of complexity of the analytical technique, however, is still low.

Type III is a procedure that is sufficiently complex that a computer is required for its use. Such models generate numerical solutions for sets of mathematical equations that could not be solved prior to the advent of modern computers. Many individuals, consultants, universities, industries, and public agencies have constructed such models.

Type IV is the same as a Type III model except that it is termed operational, meaning: 1) documentation (e.g., user's manual, description, and theory) is available; 2) the program has been well tested and its credibility established by groups other than the model developer; 3) the program is available and accessible to interested users (this does not preclude proprietary models); and 4) user support is available either from the model developer or from other groups. Although several hundred large water quality models are described in the literature, less than 100 can be termed operational. A Type IV model can thus be used by others with relative ease.

Table 8.—Surface Water Quality Model Evaluation

Issue	Generic type: I No computer, not complex	II Computer, not complex	III Computer, complex	IV Computer, complex, operational	Overall level of modeling sophistication
Nonpoint source pollution and land use					
Urban runoff:					4
Source/generation	C	C	B	B	
Transport to receiving water	—	A	A	A	
Transport in receiving water	—	C	B	B	
Impacts on beneficial use	C	C	C	C	
Control options/costs	B	B	B	B	
Erosion and sedimentation:					4
Source/generation	A	C	C	C	
Transport to receiving water	C	—	C	—	
Transport in receiving water	B	—	C	—	
Impacts on beneficial use	B	—	—	—	
Control options/costs	A	—	—	—	
Salinity:					9
Source/generation	A	A	A	—	
Transport to receiving water	A	A	A	—	
Transport in receiving water	A	A	A	A	
Impacts on beneficial use	B	C	C	—	
Control options/costs	A	—	—	—	
Other agricultural runoff:					3
Source/generation	C	C	B	B	
Transport to receiving water	—	B	A	A	
Transport in receiving water	—	C	B	B	
Impacts on beneficial use	C	C	C	C	
Control options/costs	B	B	B	B	
Airborne pollutants:					6
Source/generation	A	A	A	A	
Transport to receiving water	A	A	B	B	
Transport in receiving water	C	C	C	—	
Impacts on beneficial use	C	C	C	—	
Control options/costs	A	A	A	A	
Water quality (other than nonpoint sources and land use)					
Wasteload allocation:					7
Source/generation	A	A	A	A	
Transport to receiving water	A	A	A	A	
Transport in receiving water	A	A	A	A	
Impacts on beneficial use	C	C	C	C	
Control options/costs	B	B	B	—	
Thermal pollution:					9
Source/generation	A	A	A	A	
Transport to receiving water	A	A	A	A	
Transport in receiving water	B	A	A	A	
Impacts on beneficial use	C	C	C	C	
Control options/costs	A	A	A	A	
Toxic materials:					1
Source/generation	C	C	C	C	
Transport to receiving water	—	—	C	C	
Transport in receiving water	—	—	C	C	
Impacts on beneficial use	C	—	C	—	
Control options/costs	C	—	C	—	
Drinking water quality:					2
Source	A	—	C	—	
Treatment	A	—	C	—	
Impacts on beneficial use	C	—	—	—	
Water quality impacts on aquatic life	B	—	B	B	3

Key: A Reliable, credible modeling may be readily used for most problems of this subissue. Some models may be suitable for regulation and design.
B Same as C, but some models may be useful for planning and related purposes, and suitable for determining relative effects.
C Modeling is possible. Credibility and reliability of results is low due to weaknesses in the data base.
— Modeling of this type is not usually performed.

Overall level of modeling sophistication:
0 No models available.
10 Routine use of models of all types.

It is not possible to state categorically that one type of model is to be preferred over another—in particular that a Type IV model is to be preferred over a Type I. The appropriateness of an analytical tool depends on the particular problem and objectives of the analysis. In the most general terms, Type III and IV models have greater *potential* for accuracy and credibility than do Type I and II models. But there are many instances in which data and theoretical formulations are so lacking that the use of a complex computerized model is simply not warranted, even if one already exists. For example, the fate of toxics in the environment is of immediate concern to the public, but the various parameters and coefficients that describe the sources, sinks, and transformations of these chemicals are so ill-defined that the sophistication of toxic model formulations far outstrips the present data base. Simpler procedures are often much more credible.

The evaluation table presents a summary of informed opinion regarding the utility of models in analyzing specific issue areas. Overall, models are currently judged most successful for the issues of salinity, wasteload allocation and thermal pollution. The weakest issue is toxics, due mainly to the lack of data necessary to determine the changes these substances undergo in receiving waters.

Successful modeling for a given issue requires a good deal more than the application of sufficient modeling expertise. To model the governing principles of physical processes, the principles themselves must be well understood. Scientific understanding of biochemical phenomena related to water quality is not sufficiently advanced to permit highly accurate modeling; the governing principles of temperature, on the other hand, are relatively well documented. Data constraints place a further limitation on the utility of models—processes that are thoroughly understood can be accurately modeled only if data are available to predict conditions for the location under study. This evaluation accounts for these factors in assessing model utility, rather than simply assessing the state of the modeling art in itself.

GROUND WATER QUANTITY AND QUALITY

Introduction

Ground water systems, unlike surface water systems, are completely concealed from view; consequently, conceptual, physical, or mathematical models are the only way to achieve an understanding of their potential yields and responses to natural or man-related stresses. Simple ground water problems may be analyzed using physical hydraulic concepts and assumptions, perhaps expressed in simple paper calculations. However, more complex applications require the use of large amounts of data, gathered from multiple test wells at many different times. The only way to integrate this information involves using computers that are capable of solving hundreds or even thousands of complex mathematical expressions simultaneously.

Public agencies that issue water use permits or otherwise manage regional ground water resources must rely on models to forecast effects of ground water use. Applications range from day-to-day management of a community's ground water use to long-range planning for maximizing the utility of an entire aquifer. Models can be designed, for example, to calculate how pumping from a new well might affect local ground water levels, or to predict how far contaminants might move in a given period of time. However, models can also be designed to answer more complex questions about potential quantities of recoverable water in regional ground water systems as more and more wells are drilled and pumped. These evaluations can provide information for regulatory decisions regarding allowable limits on total ground water use, optimal pumping rates and placement of new wells, or controlling subsurface waste injection that may contaminate ground water.

The principal types of situations for which models are used include:

- changes in ground water availability;
- changes in ground water levels due to pumping from wells, land drainage, or injecting water into an aquifer;

- changes in ground water flow caused by alterations in surface water flow patterns;
- movement of contaminants through ground water systems from waste disposal or encroachment of saltwater; and
- settlement or subsidence of the land surface due to withdrawals of ground water.

The greatest limitations on the effective use of ground water models are not computer size or accuracy, but: 1) the basic understanding of physical and chemical processes in ground water systems; 2) the cost of collecting sufficient field data to describe the characteristics of the ground water system; and 3) the availability of well-trained personnel. In general, ground water quality models are much less reliable than ground water flow models. While models are widely used to address ground water availability questions, many ground water quality models have not yet been proven reliable enough for routine regulatory application.

Types of Models Used in Ground Water Resource Analysis

Ground water models are usually classified according to the physical and chemical processes they describe. The two major types are: 1) ground water flow models; and 2) contaminant transport models. Generally, ground water quantity and yield problems are analyzed with flow models, while ground water quality issues require the use of contaminant transport models. The two major model types are examined below, and ground water quantity and quality issues are analyzed in "Ground Water Quality Issues." Lastly, the section evaluates the utility of currently available ground water models.

Ground Water Flow Models

Flow models determine rates and patterns of fluid movement through soil or rock. Both the type of fluid and the nature of the soil or rock are used to further characterize the flow model. Types of fluids modeled include water only, water and air, or water and an immiscible fluid (a fluid that does not mix with water, such as gasoline). The soil or rock types may be either porous or fractured material. Flow in *porous media* is primarily through interconnected voids (open spaces) between individual grains. An example of this type of material is sandstone. In *fractured media,* water cannot move through the rock as in porous flow, but moves through cracks or cavities in the rock. In general, better estimates of flow can be made with models for porous media than for fractured media.

Saturated flow models consider the flow of water only. These models assume that water completely fills the open spaces between soil grains or rock. Data used in these models include: 1) inherent characteristics of the system, such as the transmissivity (ability to transmit fluids) and storage (ability to store fluids) characteristics of the rock or soil; and 2) changes imposed on the ground water system, such as water entering or leaving the system. Results from the model consist of calculated fluid pressures or water levels at time intervals for specific locations in the ground water system. Saturated flow models are used for almost all types of ground water quantity applications.

Above the *water table,* the open spaces between soil grains or in rock voids contain air as well as water. A model that considers a mixture of air and water simultaneously is called an *unsaturated flow model.* Data requirements for unsaturated flow models include all of those needed for saturated flow models plus data describing the reduction in transmissivity (resistance to water flow) due to the presence of air. Besides fluid pressures, the models also calculates variations in the amount of air contained in the pore spaces. Unsaturated flow models are useful for small-scale problems such as crop irrigation or water flow adjacent to landfills.

Multifluid models deal with the simultaneous flow of immiscible fluids in the soil or rock—e.g., a gasoline-water or oil-water model. These models are similar to unsaturated flow models, except that gasoline rather than air is the second component of the fluid mixture. Multifluid models can help to assess the consequences of fuel tank leaks or oil spills on land.

Contaminant Transport Models

Contaminant transport models analyze the movement, mixing, and chemical reactions of contaminated water in the native water and the soil or rock through which it flows. Like flow models, transport models are also classified by fluid and

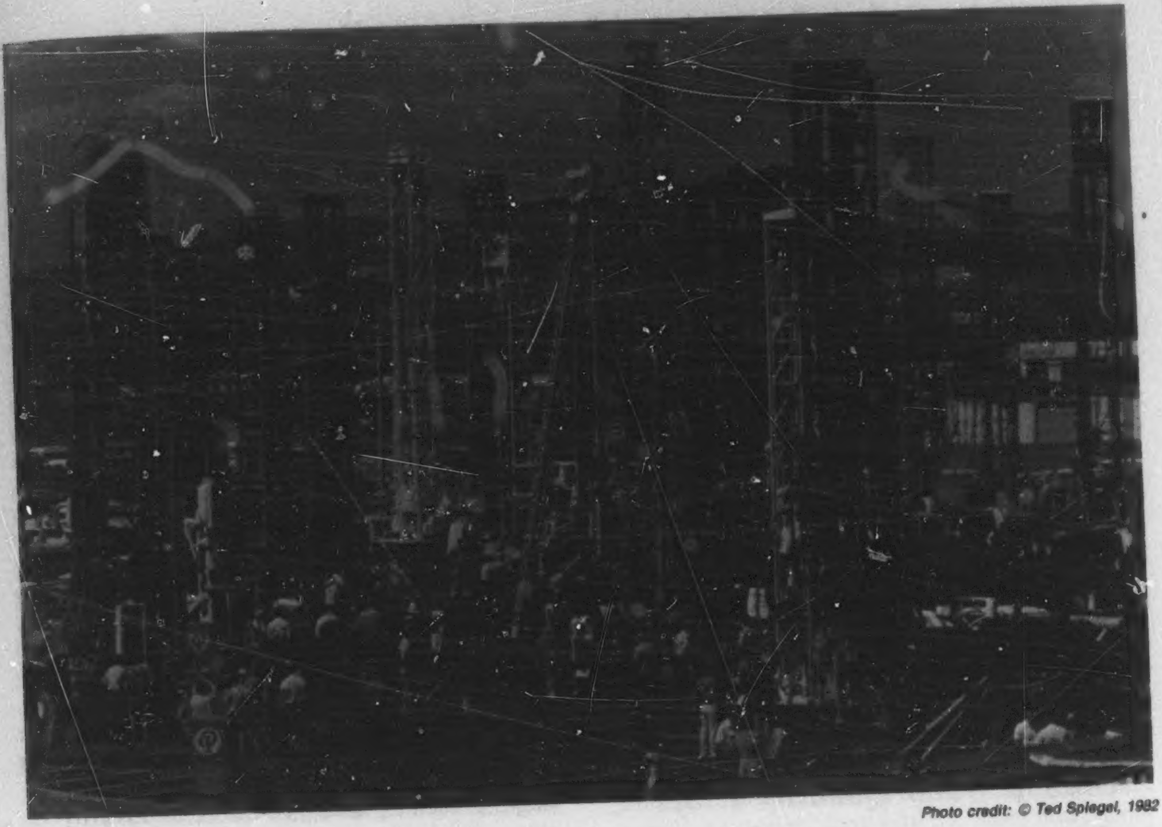

Photo credit: © Ted Spiegel, 1982

Drillers inspect a forest of the latest waterwell drilling rigs at the Pacific Northwest Exposition of the American Waterwell Association in Reno, Nev. Ground water is generally developed by small operators who own one to three rigs, learn their local aquifer's characteristics, and tap them for individual clients. Ground water models can provide extremely valuable assistance in projecting yields from individual wells, as well as in planning well spacing for maximum reliable yields

media types, as well as by the chemical reactions considered.

Three major processes control the movement and changes in concentrations of pollution in ground water: 1) movement due to ground water flow (called advection or convection); 2) the mixing of ground waters having different levels of contamination (called hydrodynamic dispersion); and 3) chemical reactions. Contaminant transport models are normally classified according to whether they consider chemical reaction. Two major types of models are generally recognized: 1) *conservative* transport models, which do not consider chemical reactions; and 2) *nonconservative* transport models, which do.

Nonconservative transport models can simulate a variety of possible chemical reactions. For example, models may consider the fate of water-borne pollutants that become fixed or adhere to the soil or rock surface, thereby coming out of solution and not moving with the water. However, while these and more complex reactions can be addressed in theory, in practice, chemical reactions are normally either ignored or are approximated by simple equations. Simple equations are used because the precise mechanisms for the chemical reaction are generally unknown or are too complicated to be used in field applications.

Data required for both conservative and nonconservative transport models include the hydrologic data discussed previously for flow models, as well as data describing mixing and chemical reactions. Models generally calculate projected concentrations of the various pollutants as they vary over time and space.

Because ground water flow is a major factor affecting the movement of contamination, pollutant transport models are necessarily extensions of ground water flow models. As a result, a contaminant transport model is, at best, as reliable as the ground water flow model to which it is coupled. For small-scale contamination problems in material that is highly variable or is fractured, estimates of ground water flow may be inaccurate, thereby reducing the reliability of transport estimates.

In addition to ground water flow, the movement of pollutants is affected by mixing and by chemical processes, both of which are poorly understood. Since quality problems are more complex than quantity problems, models dealing with ground water quality are generally less reliable than those for ground water quantity. Quality models are also considered less credible than quantity models because of their recent origin and the relative unavailability of validated models.

Ground Water Quantity Issues

Available Supplies and Optimal Yields

Models are well suited for determining the hydrologic limitations on ground water availability, or on the yield of an aquifer. Hydrologists have developed several definitions of what constitutes an aquifer's yield. One definition, "sustained yield," represents the maximum amount of water that can be removed from the system if inputs and outputs are to be balanced, with no net loss from the aquifer. The concept is based on the commonsense observation that water cannot be continually withdrawn from wells if the rate of withdrawal exceeds the natural rate of replenishment to the ground water system. A second definition, "optimal yield," incorporates political and social considerations, and refers to an optimal plan for using a ground water system, whether on a sustained basis or not. This approach attempts to maximize economic objectives and to minimize environmental impacts through legal and social constraints on the use of the ground water supply.

Computer models can be very useful tools for estimating an aquifer's response to alternative development plans. Assuming that the geometry and water-bearing characteristics of the ground water system have been adequately described, the modeler uses equations to show, for example, how water naturally enters the system from infiltration of rainfall or streamflow, how water naturally escapes from the system through discharge into surface water bodies or through consumption by vegetation, and how the extraction of water from wells affects the overall water balance.

The response of a ground water system depends not only on hydrological conditions, but also on the manner in which the ground water is withdrawn for use. For example, locating wells too close to each other may cause large water-level declines near the well field, resulting in reduced yields, dry wells, or even subsidence of the land surface. Ground water flow models can be used to address problems such as the optimal design of a well field and the extent of available supplies, and to predict water-level declines due to alternative development schemes.

Although the most frequent use of ground water flow models is for water-supply management, these models can be helpful throughout the planning stages preceding management decisions. Models also provide a framework and guide for collecting and organizing data. By matching computed model results with observed system behavior, one can gain a better understanding of hydrologic and geologic conditions. Even with limited data, the hydrologist may use a model to test alternative hypotheses of how the system behaves.

For managing, regulating, and planning the use of ground water, models that determine available supplies and optimal yields are highly reliable. However, since ground water data are derived primarily from wells, aquifers that are relatively undeveloped often have an inadequate data base for estimating potentially available yields. As the system is developed, more data become available, and earlier modeling efforts can be modified to reflect this additional information. Thus, data collection and modeling activities must be coordinated with aquifer development if reliable information about the ground water system is to be available when it is most needed—when water withdrawals are large enough to significantly affect the aquifer.

Conjunctive Use of Ground and Surface Waters

Aquifers are commonly hydrologically connected to surface lakes and streams. Ground water frequently provides the base flow to streams—the streamflow that occurs even during dry weather. During periods of low rainfall, the base flow provided by ground water is a major determinant of both the quantity and quality of surface water. A decline in ground water levels may decrease the base flow and degrade surface water quality. In other situations, surface water may recharge the ground water system. In this case, a change in the quantity or quality of the surface water would affect the ground water.

Conjunctive use models analyze the interaction between ground and surface water systems. These models may provide information about both quantity and quality aspects of surface water and ground water interrelationships, and can be used to aid in the combined management of both water sources. Ground water flow models have been employed for many different conjunctive-use situations. A typical problem of this kind involves determining the effects on surface water flows of irrigating with pumped ground water distributed through irrigation systems. The ground water flow models used for these applications are essentially the same as those used to determine optimal yields. For conjunctive use, however, the components of the model describing the interaction between ground and surface waters become critical and are consequently more complex.

During the past decade, ground water flow models have frequently been used to solve conjunctive use problems. Model reliability is nearly as high as for ground water supply and optimal yield applications; confidence is somewhat reduced, however, because quantitative estimates of the interactions between ground and surface waters are difficult to obtain. Furthermore, the scale of the surface water problem (i.e., area of influence and speed of water movement) may differ from that of the associated ground water system. This may result in an accurate description of the ground water response but a less satisfactory description of local surface water responses.

Subsidence of the Land Surface

Under certain geologic conditions, particularly where thick beds of clay underlie the land surface, heavy withdrawals of ground water may lower ground water levels to such an extent that the clays partially dry out. In some situations these clays shrink or compact, resulting in settling or subsidence of the land surface, which may cause ruptures in pipelines, cracking of building foundations, or even surface water floods. The Houston Ship Channel in Houston, Tex., is a notable example—several adjacent residential communities have essentially been abandoned because flooding by tidal waters has resulted from land surface settlement.

To model these conditions, data are needed not only for the ground water system itself but also for soil mechanics and physical properties of clay soils under dry conditions. In addition, information is needed about the surface water systems in areas where subsidence may alter drainage areas and flow patterns.

Ground Water Quality Issues

A basic understanding of ground water flow is necessary for understanding ground water quality problems. Since pollutants entering a ground water system are carried along with the water flow, many of the factors that determine quantity relationships also apply to quality models. Problems of ground water quality are likely to dominate water resource issues in the 1980's. They fall into four broad categories: 1) accidential and negligent contamination from urban and industrial areas; 2) agricultural pollutants to ground water; 3) movement of pollutants into and through ground water from waste disposal; and 4) seawater intrusion.

The disposal of wastes, in particular, involves major political issues for which the analytical capabilities of models will be useful. Wastes can be disposed of in the atmosphere, in streams and other surface water bodies, or into or on the solid earth. Each of these options has associated tradeoffs. Inland and onland disposal of either solids or liquids may contaminate ground water and cause wastes to be transported long distances from the original disposal site. Consequently, ground water hydrologists are being asked to predict the movement of contaminants to aid in designing waste-disposal systems to minimize contamination. The problem is perhaps best exemplified by the present search for a geologic disposal site for high-level radioactive wastes.

Accidental and Negligent Contamination From Urban and Industrial Areas

Unintentional ground water pollution is reported with increasing frequency. Regulatory agencies have particular difficulty in planning for emergency incidents of ground water pollution, due to the wide variety of possible contaminants and hydrogeological conditions. Contaminant transport models, in conjunction with careful hydrologic studies, can provide important information on alternative corrective measures.

This section deals with unintentional, nonagricultural contaminants to ground water. Three frequently occurring pollutant types will be discussed: 1) petroleum products; 2) industrial chemicals; and 3) road salts. For each of these, contaminant transport models can be used with varying degrees of success and confidence. Model capabilities are limited primarily by insufficient data on and understanding of the movement of contaminants through soil and rock. It is often necessary to drill numerous sampling wells to determine the extent of the contamination. Other information that is needed includes the amounts of contaminants released and the chemical reactions occurring in the soil.

Petroleum spills and leaks are serious sources of ground water contamination. Hundreds of thousands of gasoline storage tanks, thousands of miles of underground pipelines, and numerous tank trucks and railroad cars carry oil or gasoline throughout the country. Contamination from these sources is quite difficult to analyze with models. Models of the movement of oil or gasoline have been routinely employed for petroleum reservoir engineering, but have had limited application to ground water problems. Insufficient experience with these models limits their use for analyzing contaminant transport.

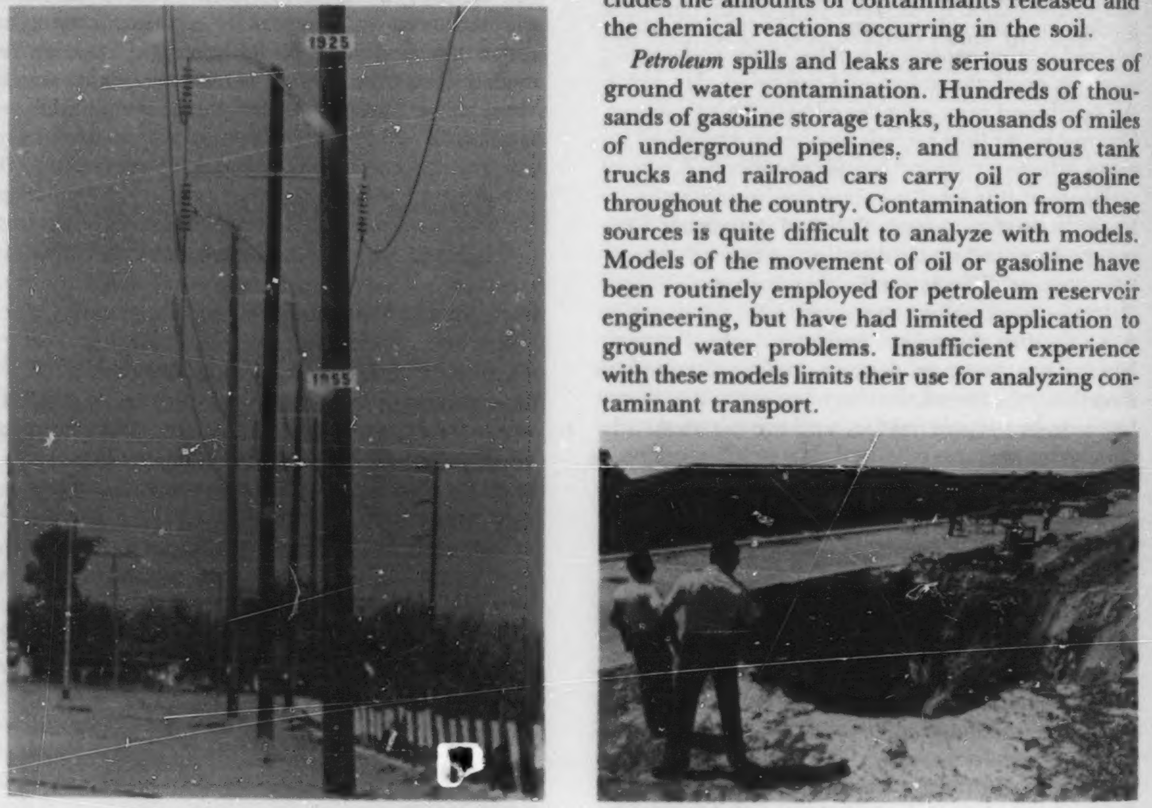

Photo credits: © Ted Spiegel, 1982

Extensive ground water withdrawal can cause land to subside on small or large scales. At left, signs on telephone poles in the San Joaquin Valley, Calif., show the sinking of the Earth's crust as a result of ground water use for irrigation since 1925. Florida sinkhole at right demonstrates a more dramatic local effect. At any scale, land subsidence in inhabited areas has enormous destructive potential; developing models to estimate the conditions under which subsidence will occur requires extensive knowledge of geology, ground water hydrology, and soil sciences

Although oil and gasoline do not generally mix with water, small concentrations of petroleum products may dissolve. These low concentrations may exceed acceptable water pollution standards. The movement of dissolved oil or gasoline can be analyzed by contaminant transport models once the nature of the dissolution process is known. These models can be used to gage the effectiveness of various cleanup procedures.

Toxic *industrial chemicals* can accidently contaminate ground water supplies in a number of ways—leaky storage tanks, tanker spills, or leaky holding ponds. The range of possible contaminants makes it difficult to use models to predict resulting pollutant concentrations. In general, for chemicals that dissolve in water but do not react with soil or rock, credible models can be developed if sufficient hydrologic data exist. However, for chemicals that are either immiscible with water or reactive with soil or rock, model reliability will be low, regardless of the amount of hydrologic data available. Still, for such reactive constituents, conservative or "worst-case" predictions can be useful for assessing the maximum pollution potential, and can be generated by assuming that no reactions occur. In these cases, model results can aid in evaluating alternative remedial measures.

Large quantities of *salts* are applied to roads during icy conditions, primarily in Northern States. Road salt is highly soluble in water; thus, shallow ground water supplies near major roads may become contaminated. In recent years, recognition of this problem has led to decreased usage of road salt. While contaminant transport models can assess the potential for ground water pollution from road salt use, the problem is not generally considered serious enough to warrant the collection of the expensive field data needed to produce credible results.

Agricultural Pollutants to Ground Water

Agriculture, because it is so widespread an activity, is an important influence on the quality of ground water. Agricultural activities can affect ground water quality through: 1) salt buildup, and 2) contamination by herbicides and pesticides.

Salt buildup is caused in two ways. In semiarid regions, fields close to streams are commonly irrigated with both surface water and pumped ground water. As the water flows through the ground and returns to the stream, it accumulates salts from the soil that are further concentrated by evaporation from soil and plants. The water returning to the stream often has high salt concentrations and is sometimes unusable for irrigation by farmers downstream.

Salt buildup can also occur as a result of fertilizers, and, to a lesser extent, from storage or disposal of livestock wastes. Fertilizer is a serious source of pollution. Nitrates—a major component of fertilizer and a type of salt—are the most common cause of ground water contamination beneath agricultural lands.

The use of *pesticides and herbicides* has expanded significantly in recent years. When pesticides and herbicides are applied to the land, they migrate downward toward ground water supplies through the unsaturated zone. They generally move slowly, and undergo chemical changes in the unsaturated zone that alter their properties. Pesticides and herbicides that are "broken down" in this manner are often not harmful when they reach the ground water. However, the greater the use of pesticides and herbicides, the higher the likelihood of producing concentrations exceeding the biodegradation capabilities of the unsaturated zone. Serious ground water pollution can result in such cases.

Models of ground water flow and transport through saturated soil and rock are generally reliable when applied to these problems. Water quality variations in an irrigated stream-aquifer system can be reliably predicted with mathematical models, if sufficient data are available.

Flow and transport in unsaturated zones are less well understood; consequently, unsaturated flow models are less reliable than saturated ground water models. As yet, no model has been developed that incorporates all the physical, chemical, and biological processes occurring in the unsaturated zone. However, many problems involving pesticide-herbicide ground water contamination can be analyzed without a comprehensive model. Simplified models are useful for assessing the effectiveness of the unsaturated zone as a barrier to potential pollutants. Results based on conservative or worst-case assumptions may be helpful for determining the effects of agricultural practices on ground water.

Movement of Pollutants Into and Through Ground Water From Waste Disposal

Several methods are commonly used for onland waste disposal:

- landfills;
- surface spreading;
- surface impoundments; and
- injection wells.

Approximately 5 pounds of solid wastes per person are produced daily in the United States. Solid waste is normally reduced in volume by compaction and placed in *landfills,* which currently number over 150,000 in the United States. When rain enters a landfill and infiltrates through the refuse, byproducts of waste decomposition dissolve in the water, producing a liquid known as leachate. Leachate can be a serious problem in nonarid regions, where rising water tables infiltrate refuse, causing contaminants to migrate into the ground water system. Such leaching of pollutants may continue for decades or even hundreds of years. Models can be used to predict the effects of alternative engineering designs on the landfill hydrology, and to predict the transport of leachate into ground waters. These models are still in initial stages of development.

Much domestic waste in the United States is processed in secondary sewage treatment plants. A common practice for disposing of these waste byproducts is to spray liquid sewage on and spread sludge over the land surface. *Surface spreading* of sewage and sewage sludge may degrade ground water quality, both through salt buildup and from heavy metals that are not removed during secondary treatment. Since this practice is similar to fertilization, modeling capabilities and difficulties are similar to those described for agricultural practices.

Surface impoundments are pits, ponds, and lagoons in which liquid wastes are stored, treated, and disposed of. These wastes contain a wide variety of organic and inorganic substances. Over 170,000 impoundments are located in the United States—many of them contain potentially hazardous wastes. Few of these impoundments have a bottom liner, and few have means for monitoring ground water quality.

Contaminants that seep from impoundments may be modified in the soil by various chemical reactions, thus reducing their harmfulness; others may move into shallow ground water and cause pollution. Studies generally show that ground water contamination creates a contaminant plume that may be well contained locally, but might extend up to a mile or more from the impoundment, depending on ground water conditions.

Actions that can be taken to alleviate contamination of ground water include:

- lining the impoundment with plastic, impervious clay, asphalt, or concrete;
- constructing collection systems such as wells for recycling; and
- reducing the movement of contaminated ground water by means of hydraulic or physical barriers.

The effectiveness of these actions can be evaluated with mathematical models. The approach to analyzing contamination from impoundments is similar to that used for landfills.

Wastewater injection wells offer an alternative to disposal of waste at or near the land surface. As of mid-1973, at least 278 industrial wastewater injection wells had been installed in 24 States, and 170 of these wells were operating. Most were between 1,000 and 6,000 ft deep and had average injection rates of less than 400 gallons per minute. As with other pollution problems, chemical and biological reactions occurring within injection wells are the most difficult to model accurately. Nonetheless, models may still be used to estimate the impact of the injection system on the natural hydrology; this, in turn, may be used to design well fields and injection schemes.

Seawater Intrusion

Cities in coastal areas often withdraw large quantities of ground water for their freshwater supplies. This decreases the seaward flow of freshwater, which may cause saltwater to move into ground water reservoirs.

The movement of seawater into drinking water supplies in coastal areas is a serious and widespread problem. Models can aid in designing well fields and pumping schemes to minimize seawater intrusion. However, for cases in which the hydrology is complex, such as a layered ground water system in which flow characteristics among the layers vary greatly, modeling results are less reliable.

Evaluation of Currently Available Ground Water Models

In table 9, models that can be applied to each of the problems previously described are evaluated according to model types employed and the models' areal scale of analysis. The evaluations are for the general level of model development in each category, rather than for any specific model. A comprehensive list of models available for ground water analysis is provided by Bachmat, et al.[1]

Two major criteria are used to evaluate each model category: 1) model reliability; and 2) credibility of model results. Models are considered reliable if they can accurately describe the important chemical and physical processes. Credible results require both a reliable model and sufficient data to run that model. For some applications, models may be reliable, but the cost and difficulty of col-

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[1] Y. B. Bachmat, et al., "Utilization of Numerical Ground Water Models for Water Resource Management," U.S. Environmental Protection Agency, report No. EPA-600/8-78-012, 1978.

Table 9.—Ground Water Model Evaluation

Spatial considerations	Model types																			
	Site										Local						Regional			
Pollutant movement, if any	Flow only				Transport w/o reactions			Transport w/ reactions			Flow only		Transport w/o reactions		Transport w/ reactions		Flow only		Transport w/o reactions	
Flow conditions	sat P	sat F	unsat P	multi fluid	sat P	sat F	unsat P	sat P	sat F	unsat P	sat P	sat F	sat P	sat F	sat P	sat F	sat P	sat F	sat P	sat F
Issues Quantity—available supplies.....	B	C									A	B					B	B		
Quantity—conjunctive use.......	B	R									A	B					B	B		
Quality—accdental petroleum products.....................				R	B	C	R						C	R						
Quality—accidental road salt.....					B	C	C													
Quality—accidental industrual chemical.....................					B	C	C	C	R	—			B	C	C	—				
Quality—agricultural pesticides and herbicides...............					B	C	C	C	R	—			B	C	C	—				
Quality—agriculture salt buildup..					B	C	C						B	C						
Quality—waste disposal landfills.					B	C	C	C	R	—			B	C	C	—				
Quality—waste disposal injection.					B	C	C	C	R	—			B	C	C	—				
Quality—seawater intrusion......				B	B	C	C						B	C					C	C

Key:
Rows — issue and subissue areas discussed in text.
Columns — model types and scale of applications; e.g., the sixth column applies to a site-scale problem in which pollutant movement is described by a transport model without chemical reactions under saturated flow condition in fractured media.

Application scale:
Site—models delaing with areas less than a few square miles.
Local—models dealing with areas greater than a few square miles but less than a few thousand square miles.
Regional—models dealing with areas greater than a few thousand square miles.

Abbreviations:
w/—with.
w/o—without.
sat—saturated ground waterflow conditions.
unsat—unsaturated flow conditions.
P—porous media.
F—fractured or solution cavity media.

Entries:
A a usable predictive tool having a high degree of reliability and credibility given sufficient data.
B a reliable conceptual tool capable of short-term (a few years) prediction with a moderate level of credibility given sufficient data.
C a useful conceptual tool for helping the hydrologist synthesize complicated hydrologic and quality data.
R a model that is still in the research stage.
— no model exists.
Blank—model type not applicable to issue area.

lecting data may prevent calculated results from being very credible. The ratings assigned for each model category are a composite of these two considerations.

The key at the bottom of table 9 describes the terms employed, and briefly summarizes the model rating scheme, the breakdown of model types, and the measurements used to define different levels of scale. Explanations of the rating scheme, and of scale and time considerations in model evaluation, are provided below:

Model Rating

A rating of "A" indicates that models are reliable and can be applied with credibility to a particular problem. It also implies that data necessary to use the model can be obtained at reasonable costs. Models with "A" ratings can be used effectively for making decisions on applicable problems.

Models rated "B" can be used for short-term predictions with confidence. The lower level of credibility implies that either some part of the processes described is not fully understood, or that data necessary to use the model may be too expensive or too difficult to obtain. These models can be applied to field problems if their limitations and capabilities are recognized. Further, if field data were collected on a continuing basis and incorporated into the model, model credibility would improve. Models with "B" ratings can also be used to investigate general problems (but not specific field applications). Conceptual investigations can be used in designing regulations and policy, e.g., for determining landfill siting criteria.

Models rated "C" have not been sufficiently validated for analyzing specific problems. Both expensive data collection and inadequate understanding of important processes are likely for these models. Models with "C" ratings have utility as conceptual tools for investigating general problems.

Models having a rating of "R" are still in developmental research stages. In the future, these models should earn a higher rating as they are validated through field use.

Models described by "—" are not presently available.

Areal Scale. The credibility of ground water models is highly dependent on the geographic scale of the study area. Most models are designed to operate at the local scale (area greater than a few square miles but less than a few thousand square miles). Therefore, more confidence may be placed in models used for this scale.

Time Scales. Ground water models project future conditions for widely varying intervals of time. Generally, the longer the range of the prediction, the less reliable it is. Ground water models normally involve planning horizons of 20 to 30 years, and each model varies in its ability to forecast future conditions. For many hazardous waste problems, the time frames needed are much longer, sometimes ranging to hundreds of years. Results from such projections are much less credible than results from models used for problems with shorter time frames. While time frames are not specifically considered in the evaluations, the effects of different time projections on the credibility of model results must be considered in evaluating specific models.

ECONOMIC AND SOCIAL MODELS

Introduction

Many different types of models and analytic techniques are used to determine the economic and social consequences of water resource activities, to forecast consumer and industrial water needs, and to analyze water resources for comprehensive river basin planning and management. Social and economic models address patterns of human behavior using theories drawn from economics, sociology, social psychology, geography, and political science.

Economic models are used to estimate the overall effects of water resource activities and regulations at both the regional and national levels, as well as to forecast economic consequences to individuals and firms. For example, an economic model can forecast changes in an industry's water use as the cost of obtaining water changes, and determine the effect of such changes on industrial output.

Social models can project population trends, estimate water demands, and analyze the social structure of a given area. They can be used to identify the groups likely to be affected by resource decisions, and their perceptions of these effects. Social models can be coupled with economic models to evaluate the societal implications of water resource regulations or projects.

The use of social and economic models is relatively new in the water resources field, as in other fields. Social and economic model use in water resource analysis has been prompted by two major regulations: 1) the Principles and Standards (P&S) of the Water Resources Council; and 2) the National Environmental Policy Act of 1969. The P&S are a group of publications that presently require consideration of the likely effects on environmental quality and national economic development of projects proposed to receive full or partial Federal funding. The P&S also require studies of the effects of proposed projects on regional development and on the social well-being of the affected area. The National Environmental Policy Act requires estimates of the social and economic effects of proposed projects. To make such estimates, social models can be used to identify the population that would be affected by the resource decision, and the extent of the likely effects. Economic models are also employed to determine the economic impacts of a project on individuals, firms and the region overall.

Several factors account for the increasing use of social and economic models. Models may provide the only available means of organizing complex information for examining the effects of an action or policy. Information derived from the conditions and scenarios assumed in a model can provide insights about the effects that may occur, and serve as a basis for common discussion of assumptions and probable outcomes. Finally, social and economic models can be used to compare the merits of proposals in terms of a particular objective, and help decisionmakers determine the costs and benefits of a proposed decision.

Both social and economic models are limited by the necessity of dealing with human behavior, which is not always predictable. Behavior is difficult to incorporate in a model except in an abstract way—identifying behavioral tendencies within a probability of outcomes. Another problem, more prevalent among social models, is that they are data-limited. Available data often prohibit quantifying and analyzing all factors involved in determining the "public interest" in any given situation. Thus, "decision" models of social and economic factors can only be used as guides—they cannot be substituted for the human decisionmaking process.

Because of the difficulty in evaluating social science models, and their less advanced state of development, these models were not formally evaluated. Few social science models are widely adaptable; moreover, such models are difficult to validate by comparing predictions to results, as is routinely done for models of physical processes. Assessing the relative utility of these models requires comparisons of previous model applications under a variety of conditions by different analysts, and necessarily involves a considerable component of subjective analysis.

Basic Analytical Characteristics

Social science models are classified by the kinds of information they generate. Three major distinctions are used to identify significant characteristics: 1) descriptive v. normative; 2) macroscale v. microscale; and 3) efficiency v. distribution of costs and benefits.

1. Perhaps the most important dimension involves the distinction between descriptive and normative models. A *descriptive* model is an empirical and historical representation of "what is." Descriptive models determine factual relationships as they exist or may be expected to occur. They are intended to include a minimum of subjective assumptions and biases.

   A *normative model* may be equally reliable and credible, but it focuses deliberately on "what should be." Normative models include substantial judgments and assumptions about goals and objectives. For example, a descriptive model of the Nation's economic output would simply report actual or expected levels of gross national product (GNP), while a normative model might include the assumption of a 5-percent annual increase in GNP as an economic goal. Most of the

Photo credit: U.S. Department of Agriculture

Water resources development can have tremendous effects on an area's ability to attract residents, industry, and related activity. Models are available to estimate how construction expenditures may directly affect local or regional economies, as well as how water facilities could affect subsequent development. In addition, models can describe how water-related development could affect demands for a wide range of public services, for example, schools, hospital facilities, roads, and other infrastructures

current social and economic models used in water resource analysis are normative, i.e., substantial a priori value judgments have been made about the goals, objectives, measures, and methods used in the model.

2. Scale is the second feature by which social science models can be categorized. Two distinct types are recognized—*macroscale models and microscale models*. Macroscale models address aggregate changes or activities. Macrolevel models include those that measure and forecast trends such as levels of national economic activity (e.g., GNP), money supply, international trade, migration patterns, etc. They are useful for providing national and regional analyses of water resource projects and programs.

   Microscale models focus on individual and/or enterprise-level behavior. They are often used in water resources for feasibility studies, environmental impact statements and other project-planning activities. Microscale models are used to address, for example, pricing, benefit/cost, social impact, and risk/benefit questions.

3. A third feature of social science models addresses the dual questions of *efficiency* and *distribution of costs and benefits*. Water resource policies or activities affect both economic efficiency and the distribution of costs and benefits. Efficiency is describable by economic models, while addressing the distribution of benefits requires a broader social analysis. Models of economic efficiency focus on means of increasing the gross supply

of goods and services. Distributive models trace changes in assets and/or income distribution among either resource owners (e.g., labor, capital, management) or major sectoral groups (e.g., farmers, industrial workers, the unemployed).

Types of Models Used for Economic Analysis

Four types of economic models are widely used for dealing with water resource issues: 1) input-output; 2) optimization; 3) econometric; and 4) simulation.

1. *Input-output models* are based on a detailed accounting of sales and purchases among each of the industries or sectors being studied. Information on purchases and sales is used to determine either the requirements for particular inputs (e.g., water) or the production of outputs (e.g., manufactured products).
2. *Optimization models* are used to determine the allocation of resources that best meets a previously specified objective (e.g., least cost), subject to some specified constraints. The technique is particularly well suited, therefore, to solving problems where both the objectives and the constraints are clearly defined. When more than one objective is considered, these models can describe the tradeoffs between the best solutions for each respective objective.
3. *Econometric models* are a less homogeneous group than the two previously discussed classes of models. The term is generally used to describe forecasting models, the structures of which have been carefully estimated from historical data. The large, national forecasting models (e.g., Chase, Wharton, Data Resource, Inc. (DRI), etc.) are of this type, as are many models tailored to regional and State needs. Econometric models are typically based on the following macroeconomic principles: 1) production determines income; 2) income determines demand; and 3) production, in turn, adjusts to demand. The interactions among production, income, and demand determine economic multiplier effects, which play an important role in economic impact analysis.
4. The fourth class of models is referred to here as *simulation models*. Economic simulation models are often input-output or econometric models that are adapted to examine the implications of different scts of assumptions. Simulation models describe the highly involved pattern of cause-and-effect relationships that operates within most social or economic systems. Once relationships are identified and the key factors have been quantified, the model is used to simulate the performance of a system over a period of time, under different sets of assumptions about the system's internal relationships and the values of external variables. Such models can calculate the incremental effects of price changes or improvements in production methods, for example.

Other Social and Economic Analytical Techniques

In addition to traditional economic analysis and the four model types identified above, an increasingly large set of social and economic analytical methods is being used in natural resource planning and policy evaluation. The methods are diverse, so they will be discussed here according to the kinds of relationships they are designed to explore.

A major consideration in planning and policy analysis is the *size and demographic structure of the population*. Demographic models, therefore, relate information about the present size and structure of the population to projected changes due to births and deaths or to population shifts. Most of these models deal with specific age, sex, and racial groups or cohorts, and are consequently referred to as cohort survival models.

Another set of analytical techniques has been developed to deal with the *demands for, and supply of, infrastructure*—factors such as housing and public facilities and services. These techniques are used by planners to determine the fiscal impacts on governments—including both expenditures and collection of revenues—of providing various levels of infrastructure services. Standard models are available to carry out these infrastructure and fiscal impact calculations, although variations among jurisdictional units require adjustment for the particular unit of government being considered.

Once economic, demographic, and public sector behavior has been accounted for, a major remaining concern is the *social structure of an area.* Few computer models have been developed to analyze this problem, but progress is being made in defining social structure, and in understanding how it is affected by natural resource decisions.

The final major area of activity for socioeconomic analysis is the *integration* of the various economic and social concerns discussed above. The models discussed above provide measures of change in the economic, demographic, fiscal, and social environment. However, the significance of these changes ultimately depends on the perceptions and values of the people who will be affected by them. Current research is underway in identifying groups that may be affected by resource decisions, and determining their evaluation of the social and economic changes that may affect them. Methods for quantifying these analyses, however, are in relatively early stages of development.

Economic and Social Issues in Water Resource Analysis

Effects of Water Pricing on Use

Severe water shortages in many locations have prompted investigation into strategies for reducing the demand for water. Water use restrictions have commonly been used for managing water use, but other methods that rely on economic incentives (water pricing and conservation subsidies) have potential for reducing the consumption of water through nonregulatory approaches.

Water demand models, which predict the response of water demand to changes in water costs, have been developed for residential, industrial, and agricultural uses. The cost of using water, as considered by these models, includes both prices paid for water delivery and other acquisition and use costs, such as costs of disposing of used water.

Residential water demand models are based on actual household water use behavior. Consumer demand theory suggests that the quantities demanded are related to water price, consumer characteristics (income, family size), and factors such as the season, and extent of outdoor use. Data are collected on household water use and on factors which affect that use. Using statistical analyses, the effect of price can be isolated from the effects of all other variables influencing residential water use.

The models analyze actual consumer responses to water prices. However, because responses to prices vary among regions and among income groups over time, model estimates will be region-, time-, and income group-specific. These models are useful planning tools, provided that adequate data are available and that analysts recognize the theoretical and statistical assumptions underlying the model.

Industrial and agricultural water demand can also be analyzed with mathematical models. Because large water users are often self-supplied, market prices for water in the conventional sense do not apply. However, analyses for these demand sectors are based on the costs borne for using water. These models consider the objectives and constraints that govern agricultural and industrial decisions about levels of production and amounts of raw materials to be used, including water. The influence of water price on use is inferred by examining the models' predictions of water use changes as water costs change.

These models are not based on observed responses to price change. Rather, they are simulations of responses that could be expected from "rational" water users with objectives and constraints similar to those described in the model. To the extent that water users deviate from the objectives and constraints assumed in the model, model predictions will be inaccurate. A number of these models have been developed; however, their use requires highly skilled analysts and good data bases.

Both types of water demand models are useful tools for water resource decisionmaking. If properly developed, they can organize complex information about the factors that determine water use, and assess the importance of price relative to other factors in determining use. Information provided by such models is helpful for developing demand management strategies, including changes in prices of publicly supplied water (e.g., at municipal systems or Federal irrigation projects) or marketing of water rights, where market prices are determined by willing buyers and sellers. These models are useful for comparing alternatives, but are less reliable for providing quantitative estimates of actual volume demands.

Cost to Industry of Pollution Control

Pollution control costs, like the availability and cost of water, are one of many factors affecting the profitability and location of industrial activity. Models are used to determine the effects of regulations on specific industries, as well as the impact of pollution control policies on the economy as a whole. Costs of pollution control can be assessed at both microeconomic and macroeconomic levels. Microeconomic costs are those associated with a particular firm or industrial group, and include direct expenditures for pollution control equipment, costs of changing production processes, and foregone production. Macroeconomic costs are gaged by calculating the effects of industry expenditures to meet environmental regulations on employment levels, the Consumer Price Index (CPI) and GNP.

Macroeconomic models are the most complex of all economic models. Their development and use requires highly skilled personnel. For example, the models of DRI, and Chase Econometrics, Inc., which are among the best known of this type, have been used to evaluate changes in macroeconomic variables in response to industry expenditures for compliance with environmental regulations. However, some analysts consider it inappropriate to use these models to measure "costs of pollution control." While the models can predict movements in the CPI or GNP, they do not estimate the economic value of a cleaner environment (e.g., reduced health care costs, workdays lost due to illness, etc.) as an offset to the cost of pollution control equipment. The reliability of these models is difficult to test; their use depends largely on the plausibility of assumptions made about inputs and the lack of credible analytical alternatives.

Microeconomic models of costs to industry for pollution control are most often optimization models, similar to those described in the above section on water demand. Models of this type can be developed for "typical firms" in specific industries. A baseline condition is first determined by applying the model without environmental regulations. Environmental regulations are then introduced as a constraint on the firm's resources and outputs. Proper interpretation of the results can provide estimates of the costs that firms incur as a result of regulations. Limitations and potentials of this type of model are similar to those of water demand models. Models of this type are used for determining the least-cost approach to environmental regulations. These models have been used to a limited extent by EPA in the water quality regulatory process. It is likely that greater use of these models will be made in the future, for reviewing existing or promulgating new environmental regulations.

Benefit/Cost Analysis

Benefit/cost analysis measures the value of a policy, program, project, or regulation in terms of economic efficiency. Procedures for calculating the benefits and costs of Federal water resource activities are outlined in the P&S of the Water Resources Council.

A relatively small portion of Federal activities in water resource protection and development is now covered by the P&S. Affected agencies (principally the Corps of Engineers, Soil Conservation Service, Bureau of Reclamation, and Tennessee Valley Authority) prepare estimates of some costs and benefits of their proposed investment projects. However, some of the most common Federal activities —e.g., waterway and discharge permits, and sewage treatment construction grants—are not required to prepare benefit/cost analyses.

Although economists have developed rigorous theoretical standards for determining the proper measure of both costs and benefits, even the most competent analysts face difficulties in conducting sound benefit/cost analyses. Many costs and benefits may be known, and yet be difficult to define or quantify accurately—in water resource activities, more incommensurable benefits tend to be encountered than incommensurable costs. Construction costs for building a dam or a sewage treatment plant, for example, are easier to estimate than the value of decreased likelihoods of flooding, or the value of cleaner water to downstream users.

When no professional consensus exists as to the monetary value of a benefit, or the probable cost of an activity, standards of accuracy for benefit/cost analysis are difficult to establish. Estimating the value of less tangible benefits necessarily involves an element of subjectivity; consequently, such estimates are affected by the assumptions of the analyst. The choice of a particular time frame or discount rate, for example, while not imparting intentional bias, may heavily influence results.

As a general rule, benefits and costs of public projects are easiest to evaluate when the resources, goods, or services produced are traded in the market economy (e.g., power production). Benefits and costs are less easy to measure if the resource, good, or service either contributes directly to a good which is traded (e.g., irrigation water as a factor in agricultural production), or if the private market offers a comparable substitute for the public project's output (e.g., railroad transportation as a substitute for river transportation). Benefits and costs are very difficult to estimate for resources, goods, or services for which few market transactions exist (e.g., recreation, wildlife habitat). In these cases, the economic value of the public project cannot be inferred from observed market prices.

Institutional limitations on the alternatives that can be considered for achieving an objective constitute another constraint to effective use of benefit/cost analysis for Federal water activities. Benefit/cost analysis is most useful when it is used as a screening device for comparing alternatives. If an agency, for example, is restricted to funding flood control structures and cannot propose purchasing flood plain development rights as a nonstructural alternative, the full power of the analytical technique cannot be effectively used.

Benefit/cost analysis is often used to support normative arguments that no actions *should* be taken unless benefits exceed costs. However, such arguments are often rejected for two reasons: First, complete measurements of economic efficiency, benefits, and costs of public actions are limited by data and time for conducting the analysis. Therefore, a benefit/cost analysis will often not reflect all economic benefits and costs. Second, economic efficiency in resource allocation is only one of several possible aspects of the "public interest" which must guide decisions. For example, the distribution of these benefits and costs among the public can be considered as important as the relative amounts of these benefits and costs. Nonetheless, benefit/cost analysis is useful for comparing and screening alternatives according to their relative contribution to the Nation's economy.

Implications of Water Resources Policy for Regional Economic Development

The regional economic impact of water resource development is an important concern that is not considered in "standard" benefit/cost analysis. To the locality or region in which a water project is proposed, the regional economic effects may be as important as the costs or benefits to the nation as a whole.

Models have been developed that estimate changes in the level of local or regional economic activities (employment or income) and/or economic base (development potential) due to projects or activities. Standard models include various forms of simple economic base studies, as well as the more complex input-output models.

In the past decade, advances have been made in regional development models for analyzing economic, demographic, and community effects associated with water resources development. The Bureau of Reclamation, for example, has developed the Bureau of Reclamation Economic Assessment Model, an economic/demographic simulation model used in both planning and impact assessment procedures. Similar tools are used by the Corps of Engineers and by regional and State water resource agencies.

These models are used to evaluate the economic effects of direct expenditures made in a region to implement a program or build a project, and the continued effects of the spending generated by these activities. Such models simulate a complex and dynamic process, accounting for multiplier effects from expenditures made in direct support of the activity (wages paid to labor, goods and services purchases locally, etc.), and assist in comparing the impacts of alternative programs and projects on the regional economy. Such comparisons can be of value for both planning and policy.

The use of these models is feasible for most skilled analysts. The Water Resources Council has published multipliers developed by the U.S. Department of Commerce for simulation purposes. However, developing the models and multipliers themselves requires special skills and extensive data.

The results of these models must be carefully interpreted. Such models are based on data that represent the existing regional economy. If the water resource activity being evaluated significantly alters the region's economic structure, the model may be invalid. The smaller the public action relative to the regional economy, the more reliable model results will be. Moreover, these models should not be used with the implicit assumption that economic activity (e.g., a new industry) will be attracted to the area solely on the basis of increased water resources development. Many economists consider water projects to be uncertain means for redistributing income, stimulating regional development, or achieving employment stability.

Clarification of the regional economic stake in water development has been and can be further aided by careful model use. This type of analysis is best suited to planning activities, such as comparing scenarios for different alternatives. If such models are used to estimate impacts with more precision, they should only assess the impact of certain, direct expenditures resulting from the public action, and only for short (1- to 5-year) time periods.

Forecasting Water Use

Models for forecasting long-range water use range from simple extrapolations of past trends to complex models that project water use in response to changing social, economic, and technological conditions.

Simple models, often termed the "requirements approach" to projection, have been favored by Federal agencies in the past. These models extrapolate historical growth rates in water use, by use category or for total consumption. The models can be modified to provide separate per capita use rates and population projections, which are then combined to produce a total water use projection. Under the latter approach, per capita use is projected to grow at historical rates and population projections are taken from separate demographic studies. The requirements approach has been called into question because it has failed to project actual water use accurately. The requirements approach also provides little assistance to the decisionmaker, since it does not indicate *why* water use changes over time.

To remedy these shortcomings, more complex economic forecasting models have been developed. Complex models are simply applications of the water demand models described above. First, the demand models are used to determine the relative importance of the various independent factors (price, income, technology, etc.) that determine consumption levels for each major category of water user. Second, future changes in these factors are projected and incorporated into a demand model to predict future demands for water. A disadvantage of the complex model approach is that it requires projections into the future for many factors, a difficult task requiring a large, credible data base.

Water use projections are only guides—"best guesses" about an uncertain future. The demand model approach does, however, serve a useful role in planning and policy. Models can be used to test the sensitivity of forecasts to different assumptions —e.g., they can identify and assess the consequences of overinvestment or underinvestment in water supply capacity.

Risk/Benefit Analysis

The consideration of uncertainty in planning or policymaking processes is a significant recent development in water resources analysis. "Risk assessment," or "risk/benefit analysis," is required by the revised P&S for situations in which uncertainty is an essential element of the planning process. Risk/benefit analysis deals with uncertain events so as to reflect both the expected outcome (in a probabilistic sense) and public attitudes toward uncertainty and risk. Public attitudes are particularly difficult to gage for those situations in which there are low probabilities of highly serious accidents.

Since the year-to-year and day-to-day variability of the hydrologic cycle encourages the presentation of information in probabilistic terms, risk analysis is a particularly suitable approach to water resources decisionmaking. A flood or a drought or a pollutant spill of a particular magnitude will cause quantifiable losses. Estimates of the probability of that size flood or drought or spill occurring transform the projected loss to a statement of risk. Safety is generally paid for with time and money. Projects and policies, with their associated costs, work to either reduce damages or the probability of an undesirable event. Judgments about acceptable levels of risk and what should be spent to reduce them are a part of the politics of water resources. Models can help in clarifying those choices.

Risk/benefit analysis organizes information so the decisionmaker can compare the reduced risk of alternative policies with the increased costs. The "benefit" side of risk/benefit analysis is generally a statement of net costs incurred by choosing a more costly alternative over a less costly one. These costs are calculated using estimation models similar to those used for benefit/cost analyses. The "risk" side of risk/benefit analysis is a statement of the probability and consequences of a particular action or occurrence. Consequently, risk/benefit analysis is not the sole domain of social scientists, but must rather be conducted by engineers, lawyers, and scientists from many disciplines.

Methods for estimating adverse health and safety risks are relatively new, but the cases in which these methods have been applied are relatively similar. One of the major shortcomings of this approach is the inadequacy of historical data to construct probability functions. Although subjective probabilities can be assigned by experts, such assignments can potentially impart biases to the analysis. The high degree of uncertainty about dose-response relationships, in particular, tends to reduce the credibility of quantitative estimates of risk.

Social Impact Analysis

The potential social impacts of water resources programs or projects have received increasing public attention in recent years. As a result, Federal agencies have begun to develop accounting methods for social effects that consider two important factors:

1. The effects of a program or project fall unevenly on different groups. For example, some groups may benefit from increased employment, some may experience shifts in recreational opportunities, others may undergo tax increases.
2. The desirability of these effects will depend on the value structures of the groups affected. The impact of activities can be perceived differently by different groups.

These two factors mean that political decisions are likely to affect certain groups differently than others. Decisionmakers need to understand not only the effects of a project, but also what the effects will mean to the affected individuals.

Regional economic development models (described above) provide a basis for considering community-level effects—particularly effects on housing, on the demand for public facilities and services, and on the overall fiscal condition of local governments. Once these consequences of a project have been determined, consideration must be given to what the Water Resources Council has referred to as "social well-being." The remaining questions are of two kinds: First, what is the effect of the project on the social structure of an area? Second, how are the economic, demographic, community, and social effects of the projects perceived by the affected people? Models and operational methods to answer these questions are still in the research stage.

Current research indicates that social structure is definable in terms of: 1) the functional groups in an area; 2) the characteristics of the groups (e.g., size, attitudes towards growth); and 3) patterns of economic, political, and social interaction among the groups (e.g., employee/employer relations and political alliances). Questions can then be asked: Will a project introduce any new groups into an area? Will it in any important way affect the characteristics of existing groups? Will it affect the way in which economic, political, or social interaction occurs among the groups? Answers to these questions constitute the social effects of a project in the same sense that economic/demographic and community effects can be defined using the models and procedures outlined above.

The next step in social well-being analysis is to determine the significance of the changes to the people affected. This requires that the distribution of effects among the various groups be known and that their individual evaluations of these effects be determined. Specifying the distribution of the effects (economic, demographic, community, social) is usually possible once both effects and groups have been clearly defined. Effects can then be evaluated, largely through direct questioning of group members or knowledgeable individuals. This part of the social assessment process constitutes "public involvement."

In projecting the social impacts of various changes, models can be used to: 1) organize information on the social factors that are affected, and 2) qualitatively determine the direction of the impacts (positive, negative, or no change). Even this qualitative information can be useful to a decisionmaker. If a systematic approach is not used, the inventory of social impacts may be incomplete.

Unified River Basin Planning and Management

River basin models consider the simultaneous use of water resources and the competing values associated with those uses. Such models are one means of assessing the "value" of water for alternative uses—both for offstream purposes and recreational, wildlife, and water quality instream uses. These models form an analytical basis for examining alternative planning and management strategies for an entire river basin. River basin models require input from a large number of disciplines as well as information from economic and social models.

Two principles are central to unified river basin planning and management:

1. River basin planning stresses comprehensive analysis of the interrelationships among water resources and social and economic activity, rather than the project-specific focus of most planning activities.
2. River basin planning emphasizes monitoring and analyses on a continuing basis, instead of only at times when specific projects are being considered.

Since the methods applied in this area are similar to, or the same as, the methods discussed in the previous sections, all of the justifications and limitations discussed in those instances apply here.

The first models developed for unified river basin planning were river basin simulation models completed during the 1960's. These models linked water resources to economic activity and demographic trends. The Susquehanna River basin model developed in the early 1960's was the first of these efforts, and demonstrated the applicability of a systems approach to river basin analysis. The general example provided by that work has been repeated many times since.

Another related application of river basin analysis has occurred principally in the Western United States. Models have been developed to analyze the economic development implications of competitive demands for water among agriculture, energy-related mining or industrial development, and in recreational stream uses. Analysis of the implications of alternative allocation schemes has generally been conducted at the river basin or State level, using simulation models with hydrologic, econometric, and demographic components. Models of this kind were first developed for the purpose of analyzing different resource management strategies in Utah in the early 1970's with the Utah Process Economic Demographic Model. Similar models now exist in many States and, among other applications, are used to analyze water resource management alternatives.

Only in a few basins have there been modeling and data collection on the scale necessary to relate in detail both water quality and water demand to subregions and sectors. To do this comprehensively requires linking physical and social models that include many subjective inputs from citizens and/or decisionmakers.

Appendixes

Appendix A

Summary of Findings From OTA Workshops on Water Resource Modeling

During the fall of 1979, the Office of Technology Assessment held two series of workshops on water resource modeling. The first series, held on October 24 and 25, addressed issues raised by staff members from 21 Federal agencies. The second series, held on November 28 and 29, brought together 37 representatives of universities and private consulting firms.

The two sets of workshops were identical in organization and operation. During the first day, both sets considered problems in model development and application; on the second day, they considered problems in model management and in the use of model results. Participants in each workshop were divided into four topical discussion groups: 1) surface water flow and supply; 2) surface water quality; 3) ground water; and 4) economic and social factors. Each group, on each day it met, identified a list of problems that emerged during the day's discussion, and then used an idea-writing session to develop solutions to the problems identified.

This appendix synthesizes the results of the two sets of workshops. Because many of the same problems were raised and discussed across topical groups and in both sets of workshops, results will be summarized by problem area. Concerns or suggestions specific to one of the series or to a topical group will be so identified.

Research and Development (R&D)— Specific Areas

Participants in each of the four topical discussion groups identified several specific research needs within their assigned areas. These needs are summarized below.

Surface Water Flow and Supply

Participants identified the following uses as research priorities:

- Online operations of water supply systems. Models need to be developed to aid managers in determining current operating rules on the basis of present and historical flow and demand conditions.
- Prediction of regional low flows and droughts. Models for stochastic analysis of regional hydrology need improvement.

Surface Water Quality

Participants in both workshop series placed high priority on two major research categories: 1) erosion and sedimentation; and 2) the fate and transport of toxicants.

For the first category, Federal participants suggested several specific areas requiring model development:

- Erosion models that predict the outcome of management alternatives, such as deforestation.
- Models that determine the fate of chemicals before they reach the stream system.
- Physically based models for sediment detachment, transport, and channel erosion. Empirically based models are currently being used.
- Sediment transport models linked with ecosystem models.

Participants agreed that improving the current state of knowledge about toxicants is urgently needed before better models can be developed to help in complementing major regulatory programs. Federal participants emphasized the need to improve understanding of:

- transport mechanisms;
- the long-term fate of toxic materials; and
- the effects of toxics on biological organisms and communities.

Federal personnel identified two further categories requiring research: reservoir and river mixing; and nonpoint source pollution. The group considered the first topic a high priority because reservoirs and rivers are receptors of toxics, and because mixing is an important component of sediment transport.

Nonpoint source pollution was considered to be increasingly important, as control of this problem becomes more cost effective than controlling point source pollutants. Specific model needs include:

- nonpoint source models that include toxics as well as sediment runoff;
- models to predict reductions in nonpoint source loadings due to various control strategies;
- models that translate nonpoint source loadings into water quality and ecological impacts; and
- models that qualify loadings under event-oriented conditions rather than on an annual basis.

Ground Water

Both series of workshops advocated R&D of models to analyze flow through aquifers that are difficult to characterize. The private sector group specifically identified flow through fractured rock as a research need; one Federal participant gave the example of radioactive waste disposal assessment as an application in which ground water flow is a highly important component.

Understanding the transport of chemicals through ground water in order to assess concentrations of contaminants was also identified as a research priority by both workshop groups. Specific suggestions included:

- improving the numerical accuracy of ground water transport models;
- incorporating chemical reaction terms into transport models; and
- researching the capability of aquifers to naturally cleanse themselves of pollutants.

The private sector group unanimously suggested that the Government sponsor research at specific waste disposal sites. Members suggested that this research be part of a national program to deal systematically with production, processing, and disposal of potentially hazardous waste.

Economic and Social

Federal representatives considered interregional microeconomics to be a research priority. Participants disagreed about both the adequacy of economic theory and the availability of data to describe interregional economic effects. Private sector modelers focused on intraregional concerns; specifically, developing methods to analyze the distributional implications of water policies. They pointed out problems of cost and availability for obtaining comparable data on a regional basis, and problems of determining the proper structure of models—e.g., the proper level of geographical aggregation, and assigning relative weights to social, economic, and enviromental concerns when characterizing the effects of water resource activities.

R&D—Methods

Two major themes emerged from workshop discussions about modeling methods: 1) improving and characterizing predictive capability; and 2) integrating alternative methods and improving their ease of use.

Methods to Measure Uncertainty

Participants in the private sector workshop stated that research on quantifying the uncertainty of predictions is needed. Specifically, they suggested that improved, standardized methods need to be developed and adopted for assessing the total uncertainty in model outputs due to errors in data, sampling, model parameter estimation, and calculation. Knowledge of risks policymakers would most like to avoid would also aid in designing methods for reporting uncertainties.

Federal participants in the area of ground water modeling identified a need to improve parameter estimation and methods for incorporating uncertainty into stochastic models. They suggested: 1) that parameter estimation procedures allow for interaction with the user to permit initial estimations, and to constrain the range of values being generated; and 2) that uncertainty of input and its impact on reliability or confidence in output always be considered during an analysis, to increase the utility and aid in the acceptance of ground water models.

Risk Characterization Methods

The surface water flow and supply group in the private sector placed high priority on two items: developing methods to characterize both long- and short-term risk in water systems, including reservoirs; and conveying the concept of risk to the public. One participant noted that risk is relative, and asserted that modelers should therefore determine the cost of not meeting some requirements when judging risk and its impacts. Another participant argued that this approach would result in guessing with computer models, which he considered less reliable than experienced judgment.

The Federal surface water flow and supply group focused on the relationships between extrapolation techniques and risk characterization. The group identified a need to improve techniques for extrapolating short-term simulation results for long-term implications. These extrapolation techniques are critical for extending the use of available data bases.

Predictive Capability

The surface water quality group from the Federal workshop recognized a need to make ecosystem models predictive at higher trophic levels. Participants stated that development of predictive models appears stalled, even though the techniques are within the state of the art. Recently developed theory has not yet been incorporated into predictive models.

The same group identified a need to improve predictive capabilities and procedures for dealing with "nonpredictive" events. One participant suggested linking stochastic models with physical models to generate long time-series of simulated "data," which, along with probability analysis, could help improve predictive capabilities. Probabilistic models could also be coupled with or used as complements to parametric and deterministic models.

The surface water quality group was also concerned over the need to improve current capabilities to model transient effects.

Model Integration and Coordination

In the private sector workshops, both the surface water quality and economic/social groups focused on the need to interrelate different types of modeling capacities. Participants in the surface water quality group stated that research should be done on methods to improve compatibility of components of water quality models. The major components of these models—sources of materials, transport to and within receiving waters, and processes occurring within receiving waters—are modeled individually and independently, often at different times and space scales. Research is needed to make the individual components compatible over the longer time and larger space scales needed for effective water quality models.

Private sector economic/social modelers suggested the need for methods to integrate their work with physically based models.

Higher Dimension Models

The need for two- and three-dimensional models for rivers and other water bodies was mentioned by the surface water quality group. One view was that for planning or screening alternatives, one-dimensional models are often, though not always, sufficient. For design purposes, two- or three-dimensional models are frequently important.

Participants suggested developing a research program to determine the type of models needed for different types of problems—relating the dimensionality of the models to different water bodies and pollutants.

Methods To Improve Model Use

Workshop participants suggested several R&D areas that might result in more efficient and productive uses of models. These include:

- using models that address a wider range of alternatives—this is of primary importance in economic models;
- developing more efficient analytical methods to reveal sensitivity relationships to the user; and
- developing improved model calibration methods, including automated and user-interactive methods.

Finally, members of the private sector surface water flow and supply group suggested that standard, accepted models for routine tasks be identified and made available. In addition, they advised that standard computer programs be designed that include a set of random numbers already specified for comparative and reporting purposes.

Data

One of the major concerns of both Federal and private participants was that data are not available to develop, calibrate, validate, and apply models. Federal modelers identified the intensive data needs of complex models, the cost of data collection, and the lack of coordination and planning of data gathering as major reasons for the unavailability of data.

Private participants tended to agree that the data-gathering process should be related more directly to the needs of models. Some suggested that modeling should precede and guide data gathering. Federal participants stressed the need for model developers to be more sensitive to the potential data requirements and data costs of their models, and suggested that data collection occur concurrently with model development.

Federal participants also agreed that improved data-collection techniques are needed to facilitate more economical data acquisition. Some participants expressed a need for greater attention to the design of data networks. Private modelers felt that the problem of inadequate data often arises because Congress and governmental agencies are unwilling to conduct data collection and review programs. Participants noted that many model types continue to be developed without adequate data to support them. They felt that certain model types should not be developed without commitments to related data-gathering activities. However, private sector participants noted that if data collection is not funded, regulations will need to be designed to accept qualitative or semiqualitative solutions.

To improve data availability, Federal participants suggested that developers, users, and data gatherers should: 1) share data and identify cooperative data needs; 2) perform sensitivity analyses to identify the most critical data needs; and 3) develop mechanisms to identify and collect long-term data. They also stressed that continual reprograming of research funds often causes long-term data needs to be neglected.

Existing Data Bases

Federal participants felt that it would be cost effective to spend additional time analyzing existing data bases. The surface water flow and supply group suggested that better agency coordination is needed to consolidate existing data bases. The group recommended that data base management specialists be employed to manage agency and interagency data systems.

National Data Bank

The private sector group held extensive discussions on the need for a national data bank. Speaking against the idea, participants stated that data banks in general are not desirable because data collection should be done with specific model formulation in mind. People in the ground water group wanted a standard data base developed for independent model comparisons. Suggestions for groups to manage a data bank included the Environmental Protection Agency (EPA) laboratory at Ada, Okla., or the Holcomb Research Institute, with funding by EPA. Some people in the surface water group wanted a national data base to supply consistent, experimental data for establishing the interrelationships between quantity and quality parameters. In the economic/social group, some members felt that an agency similar to the Census Bureau should be established to obtain reliable and consistent water resource data.

Documentation

Federal and private sector modelers strongly believed that inadequate documentation restricts the wide use of good models and contributes to the misuse of models. Participants agreed that the inadequate allocation of resources for documentation and the lack of incentives to promote good documentation greatly contribute to the problem.

Federal participants suggested the following remedies:

- Assign responsibility for documentation to an organizational unit to ensure that adequate resources are allocated. This unit might also handle technology transfer, users' assistance, etc.
- Provide incentives to modelers to allocate time to documentation efforts.
- Establish minimum guidelines for documentation.

Private sector participants tended to advocate more prescriptive approaches. They asserted that agencies should demand acceptable model documentation of all models developed with public funds. As an added incentive, agencies might withhold a percentage of the project costs until adequate documentation is received. Currently, they complained, Federal agencies such as the Office of Water Research and Technology and the National Science Foundation may end funding before the documentation project is complete.

Federal participants specified two separate components for adequate documentation: 1) a technical document; and 2) a users' document. A separate programers' document and an executive summary document were suggested by a few participants. In the private sector groups, suggested components for complete documentation of a model included: user's manual; capabilities and limitations (including explicit acknowledgments of the failure to model phenomena that are not well enough understood to be modeled); case studies and examples representing previous successes and failures; references to literature citations and names of people and organizations who have used the model; operation costs; personnel requirements; and a program listing and computer requirements.

Validation/Credibility

Federal participants identified the lack of model validation as one of the most important problems in water resource modeling, and discussed three major factors contributing to the problem.

First, resources are not adequately allocated for model validation because of its high costs. These costs might be reduced if interagency cooperation increased (e.g., cooperative interagency sampling and funding arrangements).

Second, the lack of necessary data for validation requires attention. The cost of data collection, the absence of historic data, and the time necessary to collect validation data are all limiting factors.

The third factor was the absence of guidelines for validation, identified specifically by the surface water flow and supply group. A majority of the group supported guidelines, while recognizing that guidelines would be difficult to establish because of the diversity of model designs and applications. A lead agency might be given responsibility for suggesting appropriate guidelines.

The private sector groups advocated establishing appropriate incentives for validation. Other suggestions from the private sector focused on specific procedures for model validation, requiring sensitivity analyses on all analyses made, and requiring followup investigation where model scenarios have been implemented.

Participants from the private sector also felt that models should be subject to peer review. They suggested that agencies contract for intensive review in key project stages, such as definition, completion of model development, and review of results.

Technology Transfer and Training

The majority of participants in the Federal workshop considered improving technology transfer to be a top priority; private sector participants agreed that appropriate technology transfer and Federal agency policies on technology transfer do not currently exist.

While most Federal participants believed that responsibility for technology transfer lies with the model developer, they also recognized that agencies need to provide adequate resources for technology transfer programs. They suggested that proper allocation of resources might be expedited if responsibility for technology transfer were given to a lead agency. Modelers from the private sector suggested that for agencies currently without technology transfer mechanisms, either in-house development or outside contracting would be appropriate.

Private sector participants tended to focus on training in specific disciplines and related model use as an important component of technology transfer. Participants mentioned the federally supported university training grant programs in environmental pollution and environmental health (now discontinued)—a comparable training program in water resources is needed today. They felt that funding universities to transfer new developments to the agencies should continue.

Participants from Federal agencies made a number of suggestions regarding particular methods of accomplishing technology transfer. Most agreed that the most important mechanism is one-to-one interaction between the user and the developer. For example, developers might be temporarily assigned to a user's organization to assist the user, and in addition, provide feedback for the developer. Using a central technical support staff to help solve operational problems was also suggested.

Workshops that give participants "hands on" interaction with models, and seminars, were considered good transfer techniques, especially if the developer is directly involved. Workshops and seminars designed for different levels of users (e.g., managers, technical specialists, modelers, and laymen) were also deemed necessary.

Generally, Federal participants believed that agencies need to develop incentives for developers to invest time in technology transfer activities. Many acknowledged that current agency career evaluation systems discourage modelers from providing adequate technology transfer.

Model Maintenance

Both Federal and private workshop participants strongly believed that adequate model maintenance is essential for effective model use. Private sector participants specified that Federal funding should be provided to support model maintenance and updating, but differed in their views on appropriate institutional arrangements to provide such support. Proposals included:

- designating a lead agency to track and disseminate Federal model information and revisions;
- requiring the sponsoring agency itself to maintain and update the model; and
- having the agency provide funds to the developer (or other outside group) to maintain and update models.

Federal participants proposed several specific methods to improve model maintenance:

- establish minimum guidelines and standards for model maintenance;
- prepare a written plan for long-term maintenance and assurance of adequate resources to undertake such maintenance. Year-by-year requests are inappropriate;
- assign responsibility for model maintenance to an organizational unit and assure that appropriate resources are available to carry out this goal. This group might also be responsible for model documentation, user assistance, and technology transfer, and
- establish an interagency clearinghouse to conduct a periodic survey of models, and to update and/or revise model components as needed.

Clearinghouse

Perhaps the most controversial of the subjects addressed at the workshop series was the concept of a clearinghouse for information on available models. Most participants in the private sector agreed on the utility of some form of a model clearinghouse; Federal modelers in the surface water quality and surface water flow and supply groups classified the concept as one of their 15 priority categories. The latter groups stated that a clearinghouse or inventory is needed to aid technology transfer and to serve as an information source for effective planning for future model development.

In the Federal workshop, the clearinghouse concept was conceived as having various possible levels of operation. At the simplest level, a periodic inventory might be established—e.g., a central catalog of models by subject area, listing available models, the agencies that use the model, and a contact person or agency. While such an inventory might be adequate, it would likely be difficult to administer.

A fully established clearinghouse could offer several extra services. The participants felt that responsibility for the clearinghouse should be assigned to either an interagency group or a particular agency. The clearinghouse could assist future model development by acting as a focal point for the questions of both developers and users. It could help to isolate needs for cooperative studies and determine areas of duplication.

Some Federal participants felt that technical literature, conferences, and professional meetings could adequately serve the same function. Other participants strongly believed that these mechanisms were not sufficient, partly because some operational agencies seldom publish their modeling efforts. Additional skepticism was expressed about the cost effectiveness of the clearinghouse approach.

Private sector modelers who opposed the idea asserted that it might cause centralization, resulting in red tape, regulation and ineffective action; and siphon limited funding that could be better spent elsewhere.

Coordination

Participants in both sets of workshops concurred on the lack of coordination of resources and information for model development among Government agencies. Private sector participants, while dismissing the issue of duplication as a minor problem, proposed better regional and interagency cooperation to improve coordination. Federal modelers noted the lack of mechanisms to promote interagency efforts, and the absence of incentives or precedents for agencies to work together.

Federal participants suggested a number of mechanisms for improving interagency coordination:

- a national clearinghouse and periodically published information directory to provide users with information about the quality, availability, and characteristics of models;
- an interagency model development review committee. This responsibility might be assigned to an existing committee. Some participants felt that the committee should have only an advisory role, fearing infringement on agency and scientific freedom; and
- a centralized source of expertise to advise on interagency data base creation.

Questions arose as to the practical value of some of the suggested mechanisms in view of the diversity of agency needs. Coordinating efforts through interagency meetings were considered to be too broadly philosophical to aid with actual development. However, participants recognized the importance of avoiding new model development when an existing model can be modified to serve the same purpose.

Educating Managers and Decisionmakers

The need to educate management and decisionmakers to the capabilities, assumptions, and limitations of models was stressed by participants in both workshop series. Private participants emphasized the importance of demonstrating to managers/decisionmakers that models are simply tools that provide information and insight, rather than solutions. Federal modelers were concerned about the loss of credibility suffered by models as a result of poor user understanding. They noted that users' lack of understanding of key concepts leads to model misuse and distrust of good models. User understanding was considered especially important for economic models, because they cannot be easily validated. In this case, it would be very important for the user to understand model construction in order to have confidence in the model.

Workshop participants felt that managers/decisionmakers must be provided with the following information:

- the underlying conceptual basis of models (rather than detailed mathematics);
- a taxonomy of resource models matched to a corresponding taxonomy of resource problems;
- the relative uncertainty of different models' results; and
- alternative ways to use models to solve "real-world" problems.

Responsive Model Selection and Development

Federal and private sector modelers concurred in considering the selection and development of inappropriate models a major problem, and in the need for modelers to pay greatest attention to policymakers' needs and objectives in selecting/developing appropriate models. One participant estimated that 75 percent of all models are created without a suitable set of specifications defined by the problems toward which they are directed. Federal participants further emphasized the need for users to understand their own needs and the limitations and assumptions of the models they consider.

Users often want quantitative answers to specific management questions and issues. However, according to Federal participants, the users may be unsure of what information is necessary or may perceive that models have greater capabilities than they actually do. In general, good documentation can help users understand model capabilities. The participants suggested several specific mechanisms to help users gain a better understanding of what models exist and how these models can be used to solve specific problems:

- Summary documents listing models available in each agency. These documents would briefly describe operational and developmental models and their assumptions, capabilities, limitations, appropriateness for specific applications, and the developers' names and phone numbers. These documents could stress the specific questions that available models can address.
- Seminars for users in each agency on state-of-the-art modeling efforts.

A final recommendation from private sector modelers was that repeated interaction between modelers and policymakers is necessary to respond to new objectives and problems suggested by model results. Federal participants suggested a number of specific mechanisms for accomplishing these interactions. To develop general-purpose models, the participants recommended using modern group management techniques to solicit the needs of potential users. For more specific models, improved communication between users and developers was considered necessary. Several participants suggested predevelopment working sessions to help modelers determine users' needs and help the users understand what models can provide.

Legal and Regulatory Problems

Problems mentioned by conference participants from the private sector in this category ranged from legal liabilities associated with the use of models to interjurisdictional disputes over model use. Participants suggested that agency contracts be more specific concerning the legal liability of the model developer.

Conflict among Federal, State, and local decisions based on the use of different models was also considered. Communication and cooperation among agencies, including joint model development, was suggested to alleviate these problems. However, participants also noted that different and conflicting laws, delegations of authority, and organizational interpretation of laws and models contribute to interjurisdictional disputes.

Participants from the private sector emphasized that regulations should not require specific methods. Many thought that models used in regulatory applications should stress objectives, not specific methods. Others thought that models used in regulatory applications should be required to undergo peer review and validation. Another suggestion was to establish a continuously reviewed listing of models appropriate for certain regulatory applications.

Appendix B

Summary of Model Use by Individual Federal Agencies

Introduction

This appendix summarizes water resource modeling activities of Federal agencies, using information supplied by the agencies and reviewed by OTA contractors and staff. The information was obtained from three sources: participants attending an OTA workshop, selected interviews with agency personnel, and a survey requesting agencies to indicate their model use under specific water resource laws. Agency representatives to the OTA workshop on Federal agency model use provided OTA with a written description of their agency's model use and model documentation, when available. Further information about model use and model documentation was obtained through selected interviews with agency personnel. The survey yielded information on legislation-related model use in Federal agencies as of June 1980, for agencies and offices in existence at that time (see survey form, attachment II).

This appendix describes, by agency, the water resource programs in which models are used and the types of models generally employed. The summary table of agency model use (table B-1) provides an overview of the water resource modeling activities of most of the agencies discussed in the text. The 33 water resource issues used to construct the table are listed in their unabbreviated form in table 1 of chapter 2. References for the text are listed by agency in attachment I.

U.S. Department of Agriculture (USDA)

Economics and Statistics Service (ESS)

ESS provides economic projections of short-term and long-range agricultural demands for land and water resources. Its analyses focus on how alternative development of such resources could affect the agricultural and related sectors of the economy. ESS responsibilities include basinwide and interregional economic aspects of comprehensive river basin planning.

ESS is involved in programs under the Federal Water Pollution Control Act of 1972 (Public Law 92-500), as amended by the Clean Water Act of 1977 (Public Law 95-217, hereinafter referred to as the Clean Water Act); the Soil and Water Resources Conservation Act (Public Law 95-192, hereinafter referred to as the Resource Conservation Act); and the Water Resources Planning Act (Public Law 89-80). It uses models in each program area.

Under section 201 of the Clean Water Act, which deals with construction grants for treatment plants, ESS has used models to assist local groups in Pennsylvania in choosing among alternatives for treatment facilities. ESS also uses these models as part of its own general research and development effort. For its programs in areawide waste treatment management planning, under section 208 of the act, ESS has developed a large policy model to evaluate alternatives for improving water quality in the San Joaquin Valley in California. Among the factors the model considers are land-use options, zoning, and application of irrigation water. ESS uses models under section 209 of the act as well, which addresses nationwide river basin planning. Models are also used to determine the minimum cost of composting sewage sludge in evaluating different projects under section 405 (disposal of sewage sludge) of the Clean Water Act.

ESS is also involved with regional or river basin planning under section 102 of the Water Resources Planning Act. The service uses models to estimate economic impacts of section 102 programs (regional or river basin plans). The models help project future economic conditions in rural areas under various scenarios. As is the case with all USDA river basin studies, these studies are carried with the cooperation of local sponsors.

In planning conservation programs under section 6 of the Resource Conservation Act, ESS uses models to project the likely effects of different economic conditions and conservation programs on land and water use, on erosion, and on the national economy.

ESS develops and applies computer programs for such other agencies as the Soil Conservation Service, the Water Resources Council, and the Environmental Protection Agency (EPA). These models generally incorporate economic criteria and are often of the optimizing or prescriptive type. An increasingly important service of ESS is to maintain the Land and Water Resources and Economic Modeling System (LAWREMS) described in chapter 4 of this report. This directory aids communication and technology transfer among agencies in order to reduce duplication in model development. LAWREMS contains models and data sets developed and maintained by ESS and other agencies and nongovernmental bodies.

Table B-1 - Federal Agency Model Use - January 1981

Water resource issues			ESS	Forest Service	SEA	SCS	National Weather Service	Corps of Engineers	DOE	FWS	Bureau of Reclamation	USGS	CEQ	EPA	WRC
Surface flow/supply	Hydrology	flood forecast and control		X	X	X	X	X			X	X			
		drought/low flow forecast			X	X	X	X	X		X	X			
		streamflow regulation					X	X	X		X	X			
		instream flow needs		X			X	X		X	X				X
	Use	domestic supply		X			X	X			X				X
		irrigated agriculture	X	X	X	X	X				X	X			X
		offstream use		X			X	X	X	X	X				X
		efficiency and conservation				X	X	X	X	X	X				
Surface water quality	Nonpoint Pollution	urban runoff						X		X		X		X	
		erosion & sedimentation	X	X	X	X		X		X	X	X		X	
		salinity	X			X		X		X	X	X		X	
		agricultural runoff	X		X	X		X			X	X		X	
	Quality	airborne pollutants													
		waste load allocation				X		X	X		X	X	X	X	
		thermal pollution						X	X	X	X	X	X	X	
		toxic materials							X			X	X	X	
		drinking water quality											X	X	X
		impacts on aquatic life		X			X	X	X	X	X	X	X	X	
Ground water	Quality/Qnty	available supply			X	X	X		X		X	X			X
		conjunctive use													X
		drinking water quality										X		X	X
		agricultural pollution	X							X	X			X	
		movement of pollutants							X	X	X	X		X	
		salt-water intrusion							X	X		X		X	X
Economic/Social	Economic	effects of pricing	X								X				
		cost of pollution control							X					X	
		benefit/cost analysis	X	X		X	X	X	X		X			X	
		regional economic development	X					X	X		X				
		forecasting use	X					X	X		X		X		
	Social	social impacts						X	X		X		X		
		risk/benefit analysis				X							X	X	
		competitive use demands	X	X	X			X	X	X	X		X		X
		river basin management	X	X		X	X	X	X	X			X		X

Forest Service

The Forest Service is responsible for developing, managing, and protecting lands in the national forest system. Its objectives include fostering multiple use and sustained yield of forest and rangeland resources. Beyond its research and data-gathering functions, the Forest Service coordinates planning for the forestry component of river basin surveys and investigations, as well as for the small watersheds program under the Watershed Protection and Flood Prevention Act (Public Law 83-566). It is also responsible for managing flood plains and protecting wetlands on national forest system lands.

The Forest Service carries out a large number of programs authorized under water-related legislation, and uses models in connection with many of these programs. These include:

Under the Clean Water Act:

- section 107—mine-water pollution control;
- section 208—areawide waste treatment;
- section 209—river basin planning;
- section 303—water quality standards and implementation plans; and
- section 314—clean lakes.

Under the Endangered Species Act (Public Law 93-205):

- section 7—minimizing impacts of Federal activities modifying critical habitats.

Under the Surface Mining Control and Reclamation Act (Public Law 95-87):

- section 506—surface coal mine reclamation permits; and
- section 515—environmental protection performance standards for surface coal mine reclamation.

Under the Resource Conservation Act:

- section 5—collection of data about soil, water, and related resources; and
- section 6—soil and water conservation programs.

Under Executive Order No. 11988:

- sections 5 and 6—flood plain management.

Under the Water Resources Development Act of 1974 (Public Law 93-251):

- section 73—planning nonstructural measures.

Under the Flood Control Act of 1936 and amendments (33 U.S.C. 701, et. seq.):

- sections 1-3—choosing and designing flood control structures.

The Forest Service provided detailed information on models used under the Forest and Rangeland Renewable Resources Planning Act of 1974, as amended (Public Law 93-378). Under this act the Forest Service creates and implements long-range land and research management plans at local, regional, and national levels. Models are used to estimate changes in water quality and supply under alternative management practices, and to project the economic effects of such management practices on localities. Models also aid in determining National Forest Management Act regulations—the models are used to analyze potential standards and guidelines and compare results of their applications.

Under planning activities mandated by the Forest and Rangeland Renewable Resources Act of 1978, the Forest Service uses models to compute soil moisture and streamflow in forests and rangelands. Information on soil moisture is used to determine whether and when to plant trees, and to determine viable levels of livestock per acre of rangelands. The effects of timber harvesting on streamflow are evaluated using water yield models, which determine the maximum levels of harvest consistent with preventing excessive peak flows in rivers. Models are also used to determine harvest designs which increase the water yield in watershed areas.

Science and Education Administration (SEA)

SEA is actively involved in water resources modeling as part of its mission in natural resources research. The agency's water resource modeling activities embrace a wide range of topics: climate and weather, the hydraulics of overland and channel flows, rill and interrill erosion, sediment yields from agricultural watersheds, infiltration, evapotranspiration, irrigation scheduling, subsurface drainage, and the transport of agricultural chemicals, among other topics.

In its program under section 208 of the Clean Water Act, SEA uses models to estimate the effects of land-use practices on agricultural nonpoint source pollution. This information is made available to USDA offices and to the public through USDA technical assistance programs. The agency also uses water resource models in the agricultural research it conducts under section 1402 of the Food and Agriculture Act of 1977 (Public Law 95-113). Models are used to predict the effects of different land-use practices on agricultural and nonpoint source pollution.

SEA extramural funds are used for scientific research at universities to assist in developing water resource models for resolving local, State, and regional water and water-related problems. The research may produce components and mathematical techniques for use in developing models or in checking the scientific validity of models. SEA scientists coordinate these research efforts among the respective States and the intramural research programs of SEA. In a number of cases, State and Federal scientists are cooperating on the same regional project, working on mutually developed objectives, and sharing ongoing research progress at least annually.

For the most part, SEA's modeling program aims to improve understanding of the fundamental physical, chemical, and biological processes that control or constrain crop production; assist resource conservation; and reduce present or future impacts of agricultural activities on the environment. In selected areas such as erosion and nonpoint source pollution, model development has reached the point that applying the models to resource management, planning, and policymaking is considered both feasible and justified. Examples of these models are the Universal Soil Loss Equation (USLE) model, and the Chemicals, Runoff, and Erosion from Agricultural Management System (CREAMS) model.

Soil Conservation Service (SCS)

SCS is authorized to develop and carry out a national soil and water conservation program in cooperation with landowners and operators and local, State, and Federal agencies. Its programs assist farmers, ranchers, and State and local organizations to prepare plans for resource management, including structural and nonstructural improvement for flood protection, water conservation, use and disposal of water, agricultural pollution control, environmental improvement, and rural community development.

SCS has a background of mathematical modeling dating back to the 1950's. It has applied models to flood and irrigation water control and to erosion and sedimentation problems. The principal physical models deal largely with hydrologic phenomena: generation of hydrographs; flood routing; calculation of areas, elevations, and frequencies of floods; and the mechanics of irrigation. One model is devoted entirely to applications of the universal soil loss equation, although this functional relationship also appears in many other models.

Recently, several models for economic evaluation have been developed. In fact, approximately one-half of the 30 models SCS currently uses are physical/economic integrative models that serve as planning tools to help evaluate and select conservation strategies. They are used, for example, to project floodwater damage to urban and agricultural areas, and the costs and benefits of various cropping, conservation, and land-treatment methods.

SCS reported model use under a number of legislative mandates. Under the Rural Development Act of 1972 (Public Law 92-419), the agency uses models to assist qualified local sponsors in initiating and sponsoring resource conservation and development areas.

Through the Watershed Protection and Flood Prevention Act (Public Law 83-566), SCS has primary responsibility for USDA's cooperation with local organizations in small watersheds throughout the Nation, and has specific responsibility for flood prevention measures. To carry out these responsibilities, two types of models are used—a management information model and models to determine the effects of water quality projects. The first type is a System of Watershed Automated Management Information (SWAMI), used to evaluate present programs and assess needed changes.

SCS river basin and area planning activities use models for planning and evaluating the physical, environmental, and economic aspects of water resources. Most activities include an inventory of existing resources, projections of future resource uses, and the evaluation of alternatives. Some studies develop specific models to represent unique physical processes where no existing model can be used.

Other programs involving model use that are authorized under water-related legislation include:

- The Rural Clean Water Program (Public Law 96-108), which uses models to evaluate the quality and quantity of runoff from agricultural watersheds and to evaluate alternative systems of best management practices.
- The Resource Conservation Act (Public Law 95-192), under which models are used to predict the effects of conservation programs on erosion rates and land and water use.
- The Clean Water Act (Public Law 95-217; sec. 208j), under which models are used to determine the effects of conservation practices on nonpoint source pollution from agricultural land.
- The Colorado River Basin Salinity Act (Public Law 93-320), under which models are used to determine the effects of irrigation practices in specific areas on salinity levels in the Colorado River Basin.
- The Flood Control Act of 1950 (Public Law 81-516), under which models are used to select and design floodwater-retarding structures built under this authority.
- Floodplain Management (Executive Order No. 11988), under which models are used to delineate flood plains and to predict the river stage effects of different levels of flood plain encroachment.

Department of Commerce

National Oceanographic and Atmospheric Administration (NOAA)

NOAA uses models extensively to support its numerous activities under current water resource legislation. Under the Clean Water Act, for example, NOAA's activities in basin planning, secondary treatment requirements, water qualty standards, standards for pretreatment of toxic effluents, and clean lakes (secs. 219, 301, 313, 307, and 314, respectively) all involve some model use. NOAA also uses models in its soil and water programs under the Resource Conservation Act and in its programs under the Water Resources Planning Act.

Information from NOAA models is also supplied to Federal agencies concerned with fish and wildlife habitat protection under the Fish and Wildlife Coordination Act (16 U.S.C. 661). These models help project effects on fish and wildlife habitats when planning or evaluating projects. NOAA also uses models under sections 101 and 102 of the National Environmental Policy Act (Public Law 91-190). Models are used to estimate effects on instream flow, evaluate effects on habitats and on an ecosystem's trophic relationships, and predict the probable dispersion of an oil spill.

NOAA's hydrologic service programs are managed by the National Weather Service (NWS) under authority of its Organic Act (1890) and the Flood Control Act of 1936 (§ 1,2,3j, 15 U.S.C. 313, 33 U.S.C. 706). NWS is responsible for issuing weather and river forecasts and warnings. Federal, State, and local agencies rely heavily on NWS for river and flood information for management planning, and for probable maximum precipitation estimates used in designing river and flood control structures. NWS hydrologic forecasts are important for reservoir operations, water supply management, navigation, irrigation, power production, recreation, and water quality management. Most of the information supplied is output from models.

The agency's concentrated ongoing effort to implement a system of interrelated mathematical models and predictive techniques is known as the National Weather Service River Forecast System (NWSRFS). The system incorporates models already in use and new hydrologic forecast techniques. Included are models of snow accumulation and ablation, soil moisture, streamflow routing, and unsteady open channel flow. The system also includes programs for handling and processing data and for model calibration and verification. Planned additions to NWSRFS are an enhanced reservoir operation model, and an extended streamflow prediction technique for water supply forecasting based on a conceptual watershed model. The extended streamflow prediction technique will eventually complement the current water supply forecasting procedures, which are based on statistical methods.

The first version of NWSRFS was implemented in 1971 and used for river forecasting in the lower Mississippi River basin. When fully implemented, NWSRFS will be used by all 13 NWS River Forecast Centers (RFCs) in preparing daily streamflow forecasts for more than 2,500 river forecast points and drainage areas covering approximately 97 percent of the United States.

Department of Defense

U.S. Army Corps of Engineers

The Corps of Engineers is authorized to investigate, develop, conserve, and improve the Nation's water and water-related land resources. Its programs include planning and development activities for protecting navigable waters, flood control, hydroelectric power production, flood damage reduction, flood hazard information, urban land drainage, wastewater management, shore and beach restoration and protection, fish and wildlife conservation, outdoor recreation, aquatic weed control, and environmental protection. These responsibilities include consideration of the economic, social, and environmental impacts of public works alternatives.

The Corps' mandates are based on a wide variety of water-related legislation and many are carried out with the use of models. Under the Clean Water Act, the Corps uses models to help evaluate costs and designs for water treatment facilities proposed for Federal funding pursuant to section 201 of that act. The Corps also uses models under section 1444 of the act (Federal facility pollution control).

The Corps employs models in its water resource planning activities. It uses models in its regional or river basin activities under section 102 of the Water Resources Planning Act (Public Law 89-80) and in planning and evaluating nonstructural measures under section 73 of the Water Resources Development Act (Public Law 93-251).

The Corps makes major use of models in connection with its flood control and management function. Models are used in designing and selecting flood control structures to be built pursuant to the Flood Control Act and in planning or evaluating flood-control projects. The models help assess flood peaks, compute water surface profiles, and supply data for flood damage assessment. The Corps also uses models to assist the Federal Insurance Administration in conducting flood insurance studies under the Flood Control Act.

The Corps' flood plain management programs under Executive Order No. 11988 also make use of models. Models are used to delineate the 100-year flood plain so that Federal and non-Federal interests may comply with current regulations. For example, one regulation requires that flood plain encroachment should not result in an increase in water surface elevation of more than 1 ft. The models help predict the relationship between extents of encroachment and the rise in surface water surface elevation.

The Corps' research and development in water resource modeling focuses on solving field problems. In hydrologic analysis, the Corps' Hydrologic Engineering Center (HEC) has developed a number of computer models for evaluating the expected magnitude and frequency of runoff from urban and nonurban watersheds. The principal urban runoff models are HEC-1 and STORM. HEC models have also been used to improve the operation of reservoirs during floods. Both HEC and the Corps' Waterways Experiment Station (WES) have developed several models relating to river mechanics. These models simulate hydrodynamic and sediment transport processes in rivers, lakes, and estuaries. The Corps' WES and the Coastal Engineering Research Center (CERC) have also developed and applied various models to compute hurricane surges and wave heights for design and planning purposes.

HEC has developed two reservoir-system analysis models: HEC-3 and HEC-5. These are multipurpose reservoir operation models used in planning and operating reservoir systems for flood control, hydropower, and water supply. The models have been used at the planning level to evaluate the water-supply performance and hydropower potential of existing and proposed reservoirs, and to study flood control. The HEC-5 model is currently being used in operational studies of hydropower sites selected from the Phase I screening of the National Hydropower Survey. The Corps also uses models to assess the potential impact of a partial or complete dam failure.

Both HEC and WES are developing water quality models. These models are applied to proposed Corps projects to predict overall water quality conditions and to develop appropriate design and operational criteria for attaining desired water quality levels. Models are also used to evaluate design of operational modifications for projects in which water quality problems exist.

The Corps' water resource planning models focus on flood control. Flood-damage computation procedures are part of several of HEC's flood forecast and control models. These procedures evaluate the expected damage from a series of flood events, with and without various proposed management measures. An optimization routine in the HEC-1 model analyzes various sizes and combinations of flood-control measures and allows for the evaluation of tradeoffs among facilities, performance, and cost. The HEC interactive nonstructural analysis model focuses on analyzing and formulating flood-damage reduction measures other than traditional construction projects.

Department of Energy (DOE)

Office of Environmental Assessments

Within the water resources area, DOE's Office of Environmental Assessments is concerned with the impacts of energy technologies on water resources, including the effects of energy-related pollutants on biological systems. The office is also involved in defining water and land resource requirements for energy technologies including coal gasification, coal liquefaction, uranium enrichment, geothermal development, small-scale hydroelectric development, enhanced oil recovery, and shale oil production.

The majority of the water resource models DOE uses are deterministic simulations of physical systems, and they deal primarily with three subjects: assessing surface water supply related to the potential for energy facilities development, analyzing energy-related environmental impacts including thermal effects and transport of various pollutants; and determining the economic and social effects of water use for energy development.

The Office of Environmental Assessments uses several water resource models. The Water Assessment System (WAS), located at Oak Ridge National Laboratory, is used principally for large-scale regional impact assessments. This model projects variations in streamflow, water use, and water availability over time to assess water availability for various energy scenarios. The basic geographic unit is the Water Resources Council (WRC) aggregated subregion (ASR) level. In support of WAS, the Automated Downstream Accounting Model (ADAM) calculates cumulative water availability and consumption data for surface streams in hydrologic sequence.

The Water Use Information System (WUIS) of Hanford Energy Development Laboratory is used for a number of DOE assessments. This is a computerized information system containing comprehensive data on water resources, on water availability and quality, and on electrical generating plant characteristics and operational characteristics relating to water use. Its basic geographic resolution is the WRC cataloging unit. The Los Alamos Coal Use Modeling System (LACUMS) incorporates water supply and demand sectors into a linear programming model of energy supply to facilitate water- and energy-related policy analysis. Water supply is accounted for by coal demand regions.

For large-scale water quality impact assessments, Argonne National Laboratory has developed the Argonne Water Quality Accounting System (AQUAS), a new regional screening model. The model utilizes streamflow data, measured water quality data, and residual discharge data at the accounting unit level to estimate changes in concentrations of selected pollutants. These several models are used by other agencies and organizations within and outside of DOE.

The Strategic Environmental Assessment System (SEAS) is not a water resource model per se, but it calculates wastewater residuals and regional water use for energy scenarios during the course of general environmental assessments. DOE has supported Fish and Wildlife Service development of an instream flow calculation system to quantify the effects of water consumed by the energy industry and to determine the effect on aquatic species, habitat, and the like. Its purpose is to estimate instream flow requirements that might constrain energy development.

Aquifer modeling, though not a major program, is being developed to investigate the migration of pollutants, particularly radioactive materials, from waste-disposal sites. Energy storage in aquifers has also been modeled to determine geothermal reservoir dynamics in support of this energy source. Other models investigate the effects of thermal energy releases on localized meteorology—including effects on rainfall and cloud formation—which could influence water supply.

Federal Energy Regulatory Commission (FERC)

FERC in DOE uses models under two major programs of the Federal Power Act (16 U.S.C. 803(f)): Dam Safety and Headwater Benefits.

A number of models are used to plan or evaluate projects under the Dam Safety Program. Some determine water surface profiles and downstream water velocities resulting from a dam break. Other models are used for preparing flood hydrographs, reservoir routing, and design analysis.

Payments under the Headwater Benefits Program are determined with information provided by models. These models are used to determine the energy gains at downstream hydropower plants resulting from the operation of headwater reservoirs.

FERC also indicated model use for its cooperative activities program under the Water Resources Planning Act, and for its participation in planning Federal water resources projects under the Flood Control Act of 1936 and amendments. Models are used to plan, evaluate, and review projects, and for data acquisition, statistical analysis, and water resources/hydropower system analysis.

Department of the Interior

Bureau of Land Management (BLM)

BLM is responsible for managing, conserving, and developing 174 million acres of publicly owned land in the 11 Western States and an additional 162 million acres in Alaska. BLM also administers the subsurface minerals underlying approximately 370 million additional acres throughout the Nation managed by other agencies or owned by private citizens, and on the 1.1 billion acres of Outer Continental Shelf owned by the Federal Government.

BLM's use of computer-based resource models is occasional, and is confined to selected models for site-specific analyses. Stochastic hydrologic models are used to evaluate alternate grazing systems in preparing grazing environmental impact statements. Hydraulic models are used to evaluate instream flow needs for adjudicating water rights, designing fishery habitat improvements and water facilities such as dams and water distribution systems, and in analyzing overburden materials associated with surface mining. In addition to these models, BLM uses technological guidelines developed through the use of hydrologic models to analyze various resource problems, including timber harvesting and planting techniques and their impacts on water quantity and quality; fishing improvements associated with spawning areas; flood plain identification; soil erosion; analysis of potential mineral leasing tracts; and the siting of campgrounds associated with water-based recreation.

BLM currently contributes financially to research within USDA and the Department of the Interior, as well as to various university investigators. These research projects are expected to produce a series of water resource models that will be used on a continuous basis, and to develop an additional technological guideline to address routine multiple-resource problems. In addition, BLM expects to continue to use models developed by others for solving problems related to public lands.

Bureau of Mines

The Bureau of Mines' principal responsibilities are to develop mineral resources, promote mine safety, and maintain healthful working conditions and environmental quality in the mineral industries. The bureau is concerned with the quality of water discharges in all phases of mineral production, and it engages in research to develop and improve mining technology, including methods of protecting water resources used or affected by mining.

The bureau uses models in two of the programs it carries out related to the Clean Water Act, section 107, which authorizes mine-water pollution control demonstration projects. Models are used to predict the effects of iron ore mining in the Mesabi Range of Minnesota on the area's hydrologic system. Another program involving model use is designed to develop management practices to minimize water quality problems during and after open pit mining of copper ore in Arizona. The information these models generate is furnished to mining companies to help them comply with mine-water pollution regulations.

The bureau also uses models in several other programs concerned with the effect of mining on water quality. These programs stem from various acts dealing with water resources:

- Under the Safe Drinking Water Act (Public Law 93-523), section 1421—the bureau has used models to help predict the effects of surface coal mining on the ground water regime of western Tennessee. This information is made available to mine operators to aid them in complying with existing regulations.
- Under the Surface Mining Control and Reclamation Act, section 515—the bureau is using models to predict the effect of coal mining on hydrologic regimes in Coshocton, Ohio.
- Under the Resource Conservation Act, section 6—the bureau uses models to predict the effects of coal mining on the hydrologic system, particularly ground water, in the Power River Basin in Wyoming. This information is also made available to mine operators to assist them in preparing EISs, and in complying with regulatory standards set by different agencies. This work is also related to the Surface Mining Control and Reclamation Act.

One Bureau of Mines model, UNSAT2, is used to predict seepage patterns and quantities from mine-waste impoundments. Applications of this model include analyses of the stability of spent oil shale deposits and the flow of leachates into ground water systems.

Office of Surface Mining

The Office of Surface Mining administers portions of the Surface Mining Control and Reclamation Act, using models in connection with several of its programs under title V of the act—Control of the Environmental Impacts of Surface Coal Mining.

Section 515 authorizes environmental protection performance standards for surface coal mine reclamation. The office and its contractors use models in assessing the cumulative effect of surface coal mining on an area's hydrologic regime to determine regulations and standards for protecting water quality and quantity. This information is provided to State and local agencies and to private sector interests. Under section 510 of the act, the office uses models to evaluate permit applicants' assessments of the hydrological consequences of their proposed mining activities, and as a basis for approving or denying permits. The office also uses models to evaluate protection of the hydrologic balance under the environmental protection standards set pursuant to section 515 of the Surface Mining Control Act.

Office of Water Research and Technology (OWRT)

The principal functions of OWRT are to improve technologies and methods for addressing water resource problems, train water scientists and engineers, coordinate water research, and disseminate water resource information. These tasks, carried out under the State Institute Program by university water resources research institutes in each State, are aimed at resolving local, State, and regional water and water-related problems. The State water resources research institutes and the State Institute Program are described in detail in chapter 4 of this report.

Because OWRT is not a mission-oriented agency, it does not itself use water resource models. It is active in funding model development, however. Water resource models developed by OWRT grantees and contractors span almost the entire range of issue areas and model uses. At present, OWRT is assessing the need to develop simpler, less data-intensive models than those that now exist. A concomitant concern is to adapt existing models to specific applications.

Fish and Wildlife Service

The primary responsibilities of the Fish and Wildlife Service consist of conserving and protecting fish and wildlife resources and ensuring their equal consideration with other aspects of water development planning as required by the Fish and Wildlife Coordination Act (16 U.S.C. 661). The service has a vital interest in water and related land-use programs, including diversions, impoundments, facilities development, and streamflow regulation. The service participates actively in studies leading to the formation of national, regional, or river basin plans for using water and related land resources.

The service uses models in several of its programs concerned with managing water resources for the benefit of fish and wildlife. When asked to analyze construction projects and alternatives proposed by other agencies in EISs, the service uses models to project the relative impacts of the proposed construction and its alternatives over a number of years. Models also help determine the potential effects of a project on endangered and threatened species, as well as on water flow requirements for these species. The service also uses models in surveys and investigations of the fish and wildlife impacts of water resource projects under the Federal Reclamation Act (43 U.S.C. 421 and 422), dealing with irrigation distribution systems and construction of small water resource projects, respectively.

The Fish and Wildlife Service uses models for several purposes in its programs in accordance with the Fish and Wildlife Coordination Act. Under this legislation the service recommends modifications in project design and operation consistent with sound wildlife management principles.

Some of these uses are:

- For water resources planning: the service uses models to help assess water availability and instream flows, to predict the effects on habitats surrounding such projects, and to assess the impacts of water development projects.
- For operation and management activities: the service uses models to help determine waterflow regimes and how to mitigate impacts from construction projects.

The service also acts in an advisory capacity to State and local agencies that use models to assess instream flow needs and the effects of construction and energy-related activities on aquatic populations.

For evaluating the effects of powerplant design and siting, the Fish and Wildlife Service principally uses two types of models. One type includes fairly large simulation models for investigating and predicting physical impacts of powerplant operation (specifically, cooling) on the aquatic environment. Such impacts include fish entrainment-impingement, as well as habitat modification. The service also uses a Multiple-Objective Programing (MOP) model to study regional alternatives for powerplant location. The regional energy location model (RELM) was recently modified to incorporate biological/ecological considerations into an economic optimization model. This modified model is intended to include ecological criteria in siting decisions at the earliest possible planning stage, thus reducing the likelihood of expensive litigation over the development of future energy resources.

Bureau of Reclamation

The Bureau of Reclamation is involved in developing water and related land resources in the 17 Western States. Planning such development is a multiobjective and multipurpose activity directed at irrigation, municipal and industrial water supply, hydroelectric power, flood control, navigation preservation, propagation of fish and wildlife, outdoor recreation, drainage, pollution abatement, water quality control, streamflow augmentation, watershed protection, and erosion control. All the bureau's water and land resource development activities are authorized under the Federal Reclamation Act (43 U.S.C. 421).

During the last 15 years, considerable attention has been directed toward developing and managing Western resources. As a result of this attention, a large body of water-related legislation has been passed that relates to, and has some impact on, the basic water and land resources development mission of the bureau. Sections 208, 209, and 303 of the Clean Water Act require the bureau to consider areawide wastewater treatment facilities and management, river basin planning and management, and quality standards and implementation in plans, respectively. The National Environmental Policy Act of 1969 in section 102 requires evaluation of impacts from water resource development projects both during construction and for the long term.

The Colorado River Salinity Control Act was established to define and implement effective salinity control measures to meet established water quality standards. Other legislative acts affecting the bureau's water resource development activities include: the Endangered Species Conservation Act; Executive Order No. 11988, sections 2 and 3 (flood plain management); the Water Resources Development Act, section 73, (nonstructural measures); and the Flood Control Act (building flood control structures).

To assist in accomplishing its basic water and land resource planning, development, and management mission, the Bureau of Reclamation has developed several water resource-related models. These models are used in the planning, design, and operational phases of the agency's mission, and are employed extensively to evaluate the effects of planned actions as they relate to and affect the legislation described previously. These models were not developed for any specific legislation or as a result of it, but are used as tools to assess the impacts of planned actions or change in operating strategies to see how they relate to and comply with the various statutes.

The bureau uses physical/ecological ground and surface water models, as well as various economic/social models. All of the bureau's regional offices and many of its project offices use surface water models. These models are usually developed or adapted by the office using them. Most of these models are project-specific, and simulate project operations over various time periods and with various hydrological inputs. The models are used for single projects, multiple projects, or entire river basins. Model applications include developing reservoir operation strategies; hydropower simulation; and water quality, water rights, water availability, and flood control studies.

The bureau uses models to help determine how temperature changes or peaking power releases resulting from various reservoir operation, release, and withdrawal schemes would affect downstream fisheries and recreation and power users. This information is communicated to States, localities, and other Federal agencies so that reservoir operations can comply with State and Federal fish habitat temperature guidelines, optimize power generation, and meet water user contract agreements. Models are also used to evaluate the impact of reservoir and stream operations on fish habitat and populations.

The bureau makes extensive use of simulation models to evaluate the impacts and effectiveness of irrigation systems. The models provide information for determining whether projects should be modified to exclude lands that irrigation would affect adversely. They are also used to help predict the quality and quantity of irrigation return flows and the effects of project development on aquifer quality, receiving stream quality, and chemical, physical, and biologic properties of project soils. The Return Flow Quality Simulation model has been used to calculate salinity and other ground and surface water quality changes from major irrigation projects in California, Colorado, and the Dakotas. This model can also be used to schedule the timing and amounts of water required for a variety of crops and climates.

Models are used in developing salinity level standards and in evaluating the effects of specific actions on salinity levels in the Colorado River Basin. Specifically, the models estimate the effect of future water uses on salinity and the cost effectiveness of salinity control measures for meeting established standards. The models also help determine the technical feasibility of proposed salinity control measures at point, nonpoint, and agricultural sources. In addition, the models are used to develop operating strategies for reservoirs, determine the optimum size of desalting plants and reservoirs, and maximize the water supply for all competing uses, including power, municipal and industrial, irrigation, instream flows for fisheries and recreation, and water quality.

Other types of surface water models used by the bureau include unsteady flow routing models to predict outflows and downstream routings of floods from hypothetically breached dams. These models assist in developing maps of expected inundation areas for emergency preparedness planning. The bureau also employs and continues to develop synthetic models to describe extreme storm precipitation and meteorologic conditions. These are used to determine maximum probable flood values for sizing spillways and to describe atmospheric modification potential for precipitation augmentation.

The bureau also uses a wide variety of ground water models in water resource planning, system design, and project operation. With few exceptions, these are theoretically based models that simulate the movement of both water and solutes.

A major recent effort by the Bureau has been to develop and implement the Bureau of Reclamation Economic Assessment Model (BREAM), a simulation-type model. BREAM's basic function is to provide a systematic, theoretically sound approach to projecting population, employment, and income. The bureau envisions using BREAM principally for alternative futures analyses, public involvement, projection of municipal and industrial water requirements, and economic/demographic impact assessments related to water resource construction activities and long-run uses and outputs of water resource development. The economic and demographic outputs of BREAM are also major inputs and driving variables necessary for evaluating the social impacts of water resource development activities. The bureau uses other economic models to analyze and optimize farm enterprises in determining irrigation benefits and payment capacity, and to analyze hydropower additions to existing power system networks.

The bureau has also developed data management and scheduling systems based on models of management functions. These provide for scheduling program activities, and funding and manpower requirements.

U.S. Geological Survey (USGS)

USGS conducts research on the physical features of the Nation, including its mineral and water resources. This research is based on the fields of hydrology, geology, geochemistry, and geophysics, and aims at developing new technologies and methods for appraising and conserving minerals and water. The Water Resources Division of USGS is responsible for investigating and appraising the source, quantity, quality, distribution, movement, and availability of both ground and surface water. The legal authority for this work stems from the act of October 2, 1881 (25 Stat. 505, 526), augmenting the organic act establishing USGS in 1879, and has been reinforced by the general language of annual appropriation acts for the Department of the Interior since 1894. Also, USGS has been the indirect recipient of program responsibilities under many different water resource laws that are primarily directed toward resource management agencies.

USGS uses models in connection with many of its programs. Models are used to study flow, ion transport, and geochemistry in aquifer systems; information thus generated is made available to Federal and State agencies, and to the general public. Modeling activities of the USGS Water Resources Division—in particular, the

Federal-State Cooperative Program—are described in detail in chapter 4 of this report. Models are used in connection with USGS activities relating to sections of the Clean Water Act, namely:

- section 201—grants for construction of treatment plants;
- section 311—oil and hazardous substances liability;
- section 314—clean lakes;
- section 316—thermal discharges and exemptions; and
- section 404—guidelines and permits for use of dredge or fill materials.

USGS also develops models for use by itself and others in programs under the Resource Conservation and Recovery Act (Public Law 94-580).

USGS develops models to study many aspects of quality in selected rivers of the United States. These models analyze flow and transport, dissolved oxygen, and thermal discharges. Use of these models is generally related to provisions of the Water Resources Planning Act, which requires a continuing study of the adequacy of the Nation's water supply. USGS is also developing models that will be used to assess the impact of surface coal mining on the hydrology of mined river basins, an activity relating to section 515 environmental protection standards under the Surface Mining Control and Reclamation Act.

USGS is also concerned with flood control and uses models in connection with its activities under the Flood Control Act and sections 2 and 3 of Executive Order No. 11988, dealing with flood plain management. USGS models determine flood discharges for specified recurrence intervals, flood profiles, and flood routings. The information the models produce is available to appropriate Federal, State, and local authorities and to the public.

In addition to these uses of models, USGS indicated that it uses or is developing models in connection with its activities under the following acts:

- The Safe Drinking Water Act (Public Law 93-523):
  - section 1421—protection of underground sources of drinking water; and
  - section 1444—special study and demonstration project grants for wastewater reuse, reclamation, and recycling processes.
- The Surface Mining Control and Reclamation Act:
  - section 506—surface mining permits; and
  - section 515—environmental protection standards for reclamation.
- The Resource Conservation Act:
  - section 5—data collection about soil, water, and related resources;
  - section 6—soil and water conservation programs.
- The Water Resources Development Act of 1974:
  - section 73—nonstructural measures.
- The Federal Reclamation Act:
  - 43 U.S.C. 421—irrigation distribution systems.

USGS has made significant contributions to the development of models for analyzing ground water problems. Specific areas include: physical characteristics of ground water flow, effects of ground water depletion on surface lands, flow in coupled ground water/stream systems, integration of rainfall-runoff basin models with soil moisture accounting and aquifer-flow models, interaction of economic and hydrologic considerations, prediction of pollutant transport in aquifers, and estimation of the effects of development schemes for geothermal systems. USGS is actively involved in updating and improving most of these models.

USGS surface-water modeling efforts include: flow routing in streams, estuaries, lakes, and reservoirs; sedimentation; transport of physical, chemical, and biological constituents; coupled stream-aquifer flow systems; physical hydrology for rainfall-runoff relations, stream simulations, channel geometry, and water quality; statistical hydrology for synthetic streamflows, floods, reservoir storage, and water quality; management and operations problems; and water quality problems that result from environmental pollution, such as thermal loading, pesticide pollution, and freshwater eutrophication.

Independent Agencies

Council on Environmental Quality (CEQ)

CEQ has responsibilities for national overviews of environmental quality conditions and trends. To satisfy these responsibilities, CEQ, with the cosponsorship of other agencies and organizations, has developed the UPGRADE computerized environmental analysis system. This system of models and data bases is used to analyze water quality, air quality, environmental health, and socioeconomic data. The system permits cross-analysis (e.g., water pollution vs. health) at the county level. It is an interactive system and is completely English-language prompted. Data bases on wide-ranging subject areas are being added to the system in order to broaden and deepen the system's analytical capabilities.

Environmental Protection Agency (EPA)

The responsibilities of EPA include establishing and enforcing environmental standards, conducting research on the impacts of pollution and ways to control it, and assisting CEQ in developing and recommending to the President new policies for protecting the environment.

With respect to water resources, EPA is concerned with providing water supplies that are adequate in quality for all beneficial purposes. The following EPA offices indicated use of water resource models in connection with program responsibilities.

1. Office of Research and Development (ORD)—ORD is actively involved in developing and using water resource mathematical models and predictive techniques. The major thrust of its modeling activity is to develop capabilities to translate water quality standards into maximum allowable pollution loadings, select the most cost-effective combination of controls, and assess environmental risks associated with production, transport, use, and disposal of toxic chemicals. ORD has conducted special studies of the Great Lakes, Chesapeake Bay, James River, and other areas where other EPA offices have requested technical assistance.

Two principal types of models have been developed as part of the ORD Great Lakes program. The first, a series of physical/ecological models, focus on the relationship of phytoplankton biomass to nutrient loadings. These models were developed to understand and control accelerated eutrophication in portions of the Great Lakes; they are being used to recommend guidelines for nutrient discharges. The second type of model describes the transport and fate of toxic pollutants introduced into the Great Lakes, in order to determine the levels of control required to keep environmental risks within acceptable levels.

ORD has also developed nonpoint source, toxic pollutant, eutrophication, and circulation models for the Chesapeake Bay. These address the problems of accelerated eutrophication in portions of the bay, the decline of submerged aquatic vegetation, and associated impacts on aquatic life and commerce.

ORD assists EPA's operational programs in selecting and using models to deal with specific problems. These models include urban and rural runoff models and receiving-water quality models. The models are used in determining control requirements to be placed on discharges and in planning studies required under section 208 of the Clean Water Act. ORD also provides technical assistance with the Exposure Analysis Modeling System (EXAMS), a major mathematical model for assessing the primary pathways, persistence, and fate of toxic organic chemicals in freshwater systems.

Future water resource modeling needs ORD is addressing concentrate on providing the capability to assess environmental risks associated with toxic chemicals in ground and surface water, and identifying cost-effective pollution control measures to attain and maintain water quality goals.

2. Office of Water Regulations and Standards (OWRS)—EPA's OWRS uses some models in developing guidelines for toxic and pretreatment effluent standards pursuant to section 307 of the Clean Water Act. The models OWRS currently uses address three main problem areas: the fate of pollutants discharged into receiving waters, and their effect on water quality; the quantity and quality of runoff from urban and agricultural areas, and its impact on receiving waters; and the economic effects of water pollution regulations on industries.

A principal model in the first category is EXAMS. The Water Quality Analysis Branch of OWRS currently uses EXAMS to evaluate different control strategies for selected pollutants in order to determine whether these pollutants should be subject to best available technology (BAT) requirements or to more stringent controls. The EXAMS model is being used in conjunction with agricultural runoff models, such as ARM-II, and receiving-water quality models, such as QUAL-II, for screening analyses of new pesticides.

Another major use of models of this type is in establishing and enforcing wasteload allocations for National Pollutant Discharge Elimination System (NPDES) permits. These models are used to assess the assimilative capacity of a water body and to relate stream water quality levels to pollutant discharges. The models are also used to determine whether dischargers are complying with permit allocations.

OWRS's Office of Analysis and Evaluation assesses the economic impact of water pollution regulation on industrial sectors by one of two techniques, depending on industry size. For small industries, the office performs industry-specific financial analyses to determine if compliance with point-source BAT regulations will force firms to close. The office uses econometric models to study larger industries. These models deal with capital requirements, pricing, future demand for products, and the effects of regulation on industry growth.

3. Office of Water Program Operations (OWPO)—Urban and agricultural runoff models are used to a limited degree by the national office of the Water Planning Division of OWPO in planning studies. These models are used at the State level to estimate potential runoff and to evaluate different pollution control strategies, as required under section 208 of the Clean Water Act.

4. Office of Water and Waste Management—EPA's Drinking Water Program in the Office of Water and Waste Management has the responsibility to implement provisions of the Safe Drinking Water Act, and it uses some models to improve the decisionmaking process. Under section 1412, for example, it uses health effects models as part of the background information base for setting standards and promulgating regulations. These models provide data on the health risk from exposure to contaminants in drinking water. Information from

such models has been used in the standard-setting process for radioactive and organic contaminants. The program also uses economic and benefit/cost models to determine the economic effects of alternative policy and regulatory options on the water supply industry.

Protection of underground sources of drinking water, prescribed in section 1421 of the Safe Drinking Water Act, is also a responsibility of the Drinking Water Program. Hazardous and toxic wastes have frequently been disposed of through injection into underground formations. The program uses models to provide information on the impact of injection practices on the natural system, the costs of constructing new wells, and the economic costs of shutting down existing wells. By comparing regulatory and remedial alternatives available, programs can be developed to balance the risks and costs of contamination prevention measures.

The Drinking Water Program has also conducted a major surface impoundment assessment authorized by section 1442 of the act. The assessment includes a nationwide survey of surface impoundments in order to determine their potential for contaminating ground water. Uniform criteria were developed and used to assess current and potential leakage of contaminants into ground water. These criteria include, among others, type of geology underlying the site, type of waste involved, proximity of aquifers, and capability of soil to attenuate pollutants. Based on data collected, ground water models can be developed to account for these factors in predicting an impoundment's potential for contaminating ground water.

The Drinking Water Program also uses models to evaluate State needs and capabilities in order to determine the appropriate grant amounts States receive under section 1443 of the Safe Drinking Water Act. These are financial models, but they take into consideration such factors as the number and type of injection wells in the State, the number of wells used as part of a water supply system, the geographic area, and the manpower available in the State.

Models have also been used to develop a more complete understanding of sole-source aquifers. These ground water resources may, in some parts of the country, provide the only available source of water. Models provide information on the impact of discharges and other economic activities on these sources of drinking water. Facilities that may adversely affect these aquifers include: leaking underground gasoline storage tanks, waste disposal sites, improper land use, construction of roads and buildings in the recharge zone, and pollution of adjacent streams. Once the relative impacts of sources of contamination are determined and evaluated, EPA works with State agencies and communities to establish and enforce procedures to prevent future aquifer contamination.

5. Office of Toxic Substances (OTS)—EPA's OTS uses models in several of the programs it carries out under current water resource legislation. The principal focus of its model use is the transport and fate of toxic chemicals released into the aquatic environment. Currently, models are being used in OTS for risk assessment studies, to estimate the movement of pollutants through the environment and their expected environmental concentrations. The office uses models in connection with activities under the Toxic Substances Control Act. Its models help measure the effectiveness of regulatory options in order to set standards according to sections 4, 5, and 6 of the act, which deal with testing, issuing manufacturing and processing notices, and regulating hazardous chemical substances and mixtures.

OTS uses a three-step analysis to determine whether a substance should be regulated, and, if so, how stringent the regulation should be—such regulation could range from labeling a substance as hazardous to banning its use entirely. The office first determines the exposure of human and nonhuman populations to the toxic substance. It then combines this exposure information with estimates of health and ecological effects for various exposures. Finally, the office weighs these costs against the benefits of using the substance. Models are used in accomplishing the first step of the analysis.

In addition to this use of models, OTS uses models to help design chemical testing programs and to develop monitoring studies carried out under provisions of the Toxic Substances Control Act.

OTS is also involved in programs under the Federal Insecticide, Fungicide, and Rodenticide Act of 1972 (Public Law 92-516), and uses models in conducting these programs. In its review of pesticide product registrations, OTS must consider the potential effect of the substance on ground and surface waters. In this connection, OTS uses models to assess pesticide runoff potential and the likelihood of ground water contamination by pesticides, and to predict pesticide concentration in streams. OTS also uses models for advising State and local agencies of the likelihood of ground water contamination by pesticides.

OTS mainly uses the EXAMS model, although its Evaluation Division makes limited use of ARM-II in pesticide screening studies. OTS is developing multimedia (water, air, land) models for preliminary assessments of a chemical's behavior in the environment. These models provide concentration estimates used in the exposure calculations that support risk analysis. The multimedia formulations are capable of accommodating various types of chemicals and modes of release into the environment. In addition, two ground water contamination models are being developed for OTS.

6. Office of Water Enforcement—EPA's Office of Water Enforcement uses models in connection with its

activities under the NPDES permit program and sections 301 and 316 of the Clean Water Act. The NPDES program under section 402 of the Clean Water Act requires issuance of permits to regulate discharge of pollutants into the Nation's waters. Permit limits are either technology or water quality based. When technology-based limits are unavailable or inadequate to meet water quality standards, permits are based on "best professional judgment," which may include the use of wasteload allocation or other water quality models. In addition, water quality models, dispersion models, and hydrological models are used to measure compliance with water quality standards.

Under section 316 of the Clean Water Act, which authorizes variances from thermal discharge standards, the office uses predictive studies of entrainment and impingement losses to populations of fish and shellfish in enforcing regulations governing powerplant siting. It also uses fish population models and hydrological models for the cooling intake structures program.

Section 301, which includes environmental and economic variances, demands the use of models when predictive demonstrations are needed to establish ambient concentrations of nonconventional pollutants.

National Science Foundation (NSF)

NSF does not use water resource models, nor does it directly fund the development of specific models. It does, however, fund basic research at universities that may contribute to the formulation of water resource models. Such research may also produce components and mathematical techniques that can be used in developing such models or in checking their scientific validity.

The research NSF funds in the area of water resources is for the purpose of building a firm scientific foundation, wherever possible, for empirical procedures and practices that are used in developing water resource models. Well-known examples are rainfall-runoff relationships and rainfall-soil erosion relationships.

NSF responds only to unsolicited basic research proposals in water resource engineering. During fiscal year 1979, NSF supported hydrologic and water resource studies on hydrologic data, irrigation, planning, flood forecasting, reservoir control, and surface runoff, among others. Any or all of these topics may have models associated with the project.

Water Resources Council (WRC)

WRC encourages Federal, State, and local governments and private enterprise to conserve, develop, and use water and related land resources on a comprehensive and coordinated basis. WRC also conducts periodic national water assessments to identify the Nation's critical water problems.

For its Second National Assessment in 1978, WRC developed a water supply adequacy model. This model is based on the concept of a balance between water use and water supply for both ground and surface water. The model is comprised of 21 water resource regions and 106 subregions. The subregions have data on water inflow or supply from upstream subregions, interbasin imports, precipitation runoff, and ground water. Water uses include interbasin exports, consumption, and evaporation. Ground water recharge is accounted for in the model and is not considered a loss. The hydrologic and water-use data fed into this model were derived through models incorporating precipitation records, runoff estimates, economic growth projections, and other measured or calculated variables at the water-accounting-unit level (352 nationwide). These models were produced or operated for WRC by various Federal, State, and regional agencies.

The water supply adequacy model helped identify several water supply problems. These included shortages resulting from poor distribution of supplies, instream-offstream conflicts, competition among various offstream users, ground water overdraft, quality degradation of ground and surface water, and institutional conflicts that prevent a unified approach to water management.

WRC's Water and Energy Program was authorized by the Federal Nonnuclear Energy Research and Development Act of 1974 (sec. 13 of Public Law 93-577), which directs WRC to conduct regional and site-specific water resource assessments of potential energy developments. For this purpose, a number of computerized models have been used by various WRC contractors and other Federal and State agencies, e.g., the Colorado River System Simulation (CRSS) of the Bureau of Reclamation and the respective models of the White River developed separately by Utah and Colorado. These, and similar models, evaluate flow regime, hydropower impacts, salinity and suspended solids concentrations, and other water quantity and quality changes anticipated from energy developments.

WRC presently evaluates river basin plans pursuant to section 209 of the Clean Water Act. It is testing a model that assesses water quality impacts of existing or proposed river basin management schemes—specifically, in its Yadkin-Pee Dee Level-B study.

Some river basin commissions under the purview of WRC use models to help plan or evaluate projects developed under section 102 of the Water Resources Planning Act. This section deals with regional or river basin plans and programs and their relationship to other considerations. The commissions use models to analyze the impacts of potential projects on water supply, to estimate depleted flows at key gaging stations, and to compare the cost effectiveness of alternative wasteload reduction strategies.

Federal Emergency Management Agency

The Federal Emergency Management Agency, through the Federal Insurance Administration (FIA), administers the National Flood Insurance Program as established by the National Flood Insurance Act of 1968 (Public Law 90-488). The program provides flood insurance availability to property owners within communities that adopt and enforce minimum flood plain management measures to mitigate future flood losses. The act also requires the identification of flood-prone areas and risk zones within such areas.

Flood insurance studies are conducted for individual communities to establish flood plains, floodways, regulatory flood elevations, and insurance risk zones. These data are often developed using models and are subsequently provided to participating communities as the basis for their flood plain management program. They are also used to establish actuarial flood insurance rates.

Several different hydrologic models have been used by FIA to establish flood flow frequencies and for flood hydrograph routing. The most commonly used hydrologic models are the HEC-1 Flood Hydrograph Package, developed by the Corps of Engineers, and the TR-20 Computer Program for Project Formulation, developed by SCS. These models simulate the rainfall-runoff process on watersheds and flood hydrograph progression in downstream channels.

Several hydraulic models have been used to establish flood elevations and floodways in streams. The most commonly used hydraulic models are the HEC-2 Water Surface Profile Package, developed by the Corps of Engineers, WSP-2 (TR61) and FLDWY (TR-64), developed by SCS, and E431, developed by USGS. These models simulate open channel steady uniform flow using the standard step backwater method.

FIA has also developed two coastal storm surge models, including one for northeasters and one for hurricanes. These models utilize joint probability techniques and coastal hydrodynamic principles to establish regulatory flood elevations on the Atlantic and Gulf coasts of the United States. A finite element model has also been established to simulate storm surges in the Chesapeake Bay.

Nuclear Regulatory Commission (NRC)

NRC water resource activities are related to determining hydrologic factors in nuclear facility site evaluations, ecological effects of water use, and radionuclide transport in ground and surface waters. NRC has used models in connection with all of these programs. For example, to comply with regulations under section 102 of the National Environmental Protection Act, NRC used models to evaluate powerplant intake effects on Hudson River striped bass.

NRC has specific responsibilities under the Uranium Mill Tailings Radiation Control Act and the Atomic Energy Act. Under the first act, NRC uses models to determine the movement and concentration of ground water pollutants from uranium mill tailings. Information provided by these models was used to prepare a generic environmental impact statement on uranium milling and associated rule changes. NRC also uses models to support various licensing actions. Models help support licensing decisions for uranium mills, tailings disposal systems, and uranium extraction operations. Models also help measure compliance with regulations and license conditions.

Under the Atomic Energy Act, NRC uses models to help it evaluate proposed sites for nuclear powerplants, fuel cycle facilities, and waste disposal sites. Models are used to help determine whether a plant's water supply is adequate for safety-related functions, as specified in regulations. NRC also uses models to evaluate whether proposed nuclear facilities are in compliance with regulations governing flood protection.

Models have been used by NRC in carrying out its responsibilities under the Atomic Energy Act to limit radioactive liquid effluents to ground and surface waters. NRC is using models to help prepare an EIS and to formulate proposed regulations governing the disposal of low-level radioactive waste and low-activity bulk solid waste. The models are presently being used to evaluate siting criteria and alternative disposal techniques in terms of radionuclide transport and concentrations at site boundaries. When disposal site regulations are adopted, site-specific models will be used to determine whether adequate protection exists to prevent radionuclide migration from exceeding acceptable limits. Models are also used to help determine whether other types of nuclear facilities are in compliance. These models help evaluate potential concentrations of radionuclides in ground and surface waters as a result of both accidental and normal releases.

NRC provides assistance to States in the use of models to evaluate radionuclide migration from disposal sites. This is done as part of the agreement State program, through which certain States, pursuant to section 274 of the Atomic Energy Act, have entered into an agreement with NRC for assuming regulatory control of byproduct, source, and small quantities of special nuclear materials.

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ATTACHMENT I.—REFERENCES BY AGENCY

Department of Agriculture

Economics and Statistics Service

1. Dyke, P., and Hagen, L., Resource Systems Program, Natural Resource Economics Division, Economics, Statistics, and Cooperative Service, USDA, *Land and Water Resource and Economic Modeling System, LAWREMS Directory,* version 1, January 1979.
2. Land and Water Conservation Task Force, "LAWREMS, Land and Water Resources and Economic Modeling System, Current Capabilities, Conceptual System, Future Options, Final Draft," USDA, December 1978.
3. Weisz, R. N., National Systems Section, Natural Resource Economics Division, Economic, Statistics and Cooperative Service, USDA, October 1979.

Forest Service

4. Forest Service, USDA (unknown title), sec. 2, Hydrologic and Soils Simulation Programs, pp. 32-65.
5. Group Leader, Watershed Systems Development Group, Forest Service, USDA, Userguide Abstracts.

Science and Education Administration

6. Data Systems Application Division of Agricultural Research Service, USDA, *File of Agricultural Research Models (FARM),* November 1977.
7. Knisel, W. G., "A Field Scale Model for Estimating Chemicals, Runoff, and Erosion From Agricultural Management Systems," Science and Education Administration, USDA.
8. Wischmeier, W. H., and Smith, D. D., "Predicting Rainfall Erosion Losses—A Guide to Conservation Planning," Science and Education Administration, USDA, agriculture handbook No. 537, 1978.

Soil Conservation Service

9. Ecology Simulations, Inc., Athens, Ga., "SECWATS: A Simulation Concept and Model for Assessment, Evaluation and Optimization of Southeastern Coastal Plain Stream Modification Projects, With Application to Horse Range Swamp, South Carolina." contract No. AG SCS-00111, submitted to: SCS, USDA, June 1, 1978.
10. King, Arnold D., "Universal Soil Loss Equation," Soil Conservation Service, 1979.
11. Pasley, R. M., Dempster, T., Stierna, J., Caldwell, B., King, A., and Evans, G., interviews with Soil Conservation Service and USDA personnel, Aug. 30, 1979.
12. Soil Conservation Service, "Executive Summary of Responses to Objectives," USDA, Oct. 19, 1979.
13. Soil Conservation Service, Farmer Decision and Conservation Simulation Model, draft RLC: PEB, USDA, Aug. 23,1979.
14. Soil Conservation Service and Stanford Research Institute, draft, "Documentation of the SRI Methodology for RCA Evaluation," September 1979.
15. Soil Conservation Service, West Technical Service Center, *User's Guide to the Irrigation Method Analysis Program, IRMA,* Colorado River Basin Salinity Control Studies and Irrigation Planning, USDA, February 1978.
16. Metcalf and Eddy, Inc. (sponsored in part by USDA), *Process Design Manual for Land Treatment of Municipal Wastewater,* October 1977.
17. Soil Conservation Service, USDA, "Land Damage Analysis," attachment, 1976.
18. Soil Conservation Service, Engineering Division, *WSP-2 Computer Program,* technical release No. 61, USDA, May 1976.
19. Soil Conservation Service, Special Projects Division, *User's Guide to the SCS Automated Irrigation Water Use Requirements Model Utilized in the 1975 National Water Assessment Program,* USDA, May 1975.
20. Soil Conservation Service, Engineering Division, *Urban Hydrology for Small Watersheds,* technical release No. 55, USDA, January 1975.
21. Soil Conservation Service, "Urban Floodwater Damage, Economic Evaluation," attachment 28, USDA, 1976.
22. Soil Conservation Service, Engineering Division, *Computer Program for Project Formulation, Structure Site Analysis,* technical release No. 48, USDA, February 1971.
23. Soil Conservation Service, Economics Division, ECON2, Economics—Floodwater Damages, program description, Apr. 1, 1969.
24. Soil Conservation Service, Engineering Division, *Computer Program for Project Formulation, Hydrology,* technical release No. 20, 1965.

25. Soil Conservation Service, Applied Conservation Effects System, briefing paper, USDA.

Department of Commerce

NOAA: National Weather Service

26. Curtis, D. C., and Schaake, Jr., J. C., "The NWS Extended Streamflow Prediction Technique," presented at the Engineering Foundation Conference: Water Conservation—Needs and Implementation Strategies, held at Franklin Pierce College, Rindge, N.H., July 9-13, 1978.
27. Fread, D. L., "National Weather Service Operational Dynamic Wave Model," presented at Numerical Modeling for Engineers Symposium, Vicksburg, Miss., U.S. Army Corps of Engineers, Waterways Experiment Station, Apr. 17-21, 1978.
28. Fread, D. L., "The NWS Dam-Break Flood Forecasting Model," presented at Dam-Break Modeling Seminars at Kansas City, Mo., Sept. 18-22, 1978.
29. Hydrologic Research Laboratory, National Weather Service River Forecast System Forecast Procedures, NOAA technical memorandum NWS-HYDRO-14, Silver Sring, Md., Department of Commerce, 1972.
30. Krsysztofowicz, R., Davis, D. R., Ferrell, W. R., Hosne-Sanaye, S., Perry, S. E., and Robotham, H. R., "Evaluation of Flood Forecasting Response Systems II," report to Hydrology Laboratory, Office of Hydrology, National Weather Service, NOAA, Department of Commerce, contract No. 6-35229, Reports on Natural Resource Systems No. 33, University of Arizona, Tucson, Ariz., 1979.
31. Office of Hydrology, National Weather Service, "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
32. Ostrowski, J. T., National Weather Service, "Products Useful for Reservoir Regulation," Hydrologic Research Laboratory, National Weather Service, NOAA, Silver Spring, Md., mimeograph, 1979.
33. Peck, E., and Hudlow, M., staff, Office of Hydrology, National Weather Service, NOAA, Department of Commerce, personal interview, Aug. 29, 1979.
34. Schaake, Jr., J. C., "Use of Mathematical Models for Hydrologic Forecasting in the National Weather Service," in *Proceedings of the EPA Conference on Environmental Modeling and Simulation,* W. R. Ott (ed.), report No. EPA-600/9-76-106 (Cincinnati, Ohio: Environmental Protection Agency, 1976).
35. Twedt, T. M., Schaake, Jr., J. C., and Peck, E. L., "National Weather Service Extended Streamflow Prediction," in *Proceedings of the Western Show Conference,* Albuquerque, N.M., Apr. 19-31, 1977.

Department of Defense

U.S. Army Corps of Engineers

36. Boyd, M. B., "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
37. Eichert, B. S., and Bonner, V. R., HEC Contribution to Reservoir System Operation, technical paper No. 63 (Davis, Calif.: Hydrologic Engineering Center, U.S. Army Corps of Engineers, August 1979).
38. Gundlach, D. L. and Thomas, W. A., "Guidelines for Calculating and Routing a Dam-Break Flood," research note No. 5 (Davis, Calif.: Hydrologic Engineering Center, U.S. Army Corps of Engineers, May 1977).
39. Hydrologic Engineering Center, Urban Stormwater Runoff "STORM," Generalized Computer Program 723-58-62520 (Davis, Calif., Hydrologic Engineering Center, U.S. Army Corps of Engineers, May 1976).
40. Hydrologic Engineering Center, Computer Program Abstracts (Davis, Calif.: Hydrologic Engineering Center, U.S. Army Corps of Engineers, December, 1978).
41. Hydrologic Engineering Center, "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
42. Robey, D. L., "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
43. Roesner, L. A., Nichandros, H. M., and Shubinski, R. P., "A Model for Evaluating Runoff-Quality in Metropolitan Master Planning," technical paper No. 58 (Davis, Calif.: Hydrologic Engineering Center, U.S. Army Corps of Engineers, April 1974).
44. Walski, Thomas M., "MAPS—A Planning Tool for Corps of Engineers Regional Water Supply Studies," Water Resources Bulletin, vol. 16, No. 2, April 1980.

Department of Energy

Office of the Environment

45. Osterhoudt, Frank H., "Response to OTA Questionnaire: Task Force on Water Resource Modeling in the Federal Agencies," personal correspondence, November 1979.
46. Owen, P. T., Dailey, N. S., Johnson, C. A., and Martin, F. M., "An Inventory of Environmental Impacts Models Related to Energy Technologies," ORNL/EIS-147, February 1979.
47. Shepard, A. D., "A Spatial Analysis Method of Assessing Water Supply and Demand Applied to Energy Development in the Ohio River Basin," ORNL/TM-6375, August 1979.
48. Shriner, C. R. and Peck, L. J. (eds.), "Inventory of Data Bases, Graphics Packages, and Models in Department of Energy Laboratories," ORNL/EIS-144, November 1978.
49. Shriner, C. R. and Peck, L. J. (eds.), "Water Resource Management, Planning and Policy Models in Department of Energy Laboratories," November 1978.

Department of the Interior

Bureau of Land Management

50. Bureau of Land Management, "Water Resource Modeling in the Bureau of Land Management," personal correspondence, 1979.

Bureau of Mines

51. Bloomsburg, G. L. and Wells, R. D., "Seepage Through Partially Saturated Shale Wastes: Final Report," contract No. H0252965, September 1978.
52. Bureau of Mines, "Response to OTA Questionnaire: Task Force on Water Resource Modeling," personal correspondence, November 1979.
53. Hittman Associates, Inc., "Monitoring and Modeling of Shallow Groundwater Systems in the Powder River Basin: Second Annual Technical Report," No. H-D0166-78-757F, February 1979.

Office of Water Research and Technology

54. Roefs, Theodore G., "Response to OTA Questionnaire: Task Force on Water Resource Modeling," personal communication, October 1979.

U.S. Fish and Wildlife Service

55. Hyra, Ronald, "Methods of Assessing Instream Flows for Recreation," FWS/ORS-78/34, Fish and Wildlife Service, Fort Collins, Colo., June 1978.
56. U.S. Fish and Wildlife Service, annotated list of water resource models developed for or by the U.S. Fish and Wildlife Service, 1979.
57. U.S. Fish and Wildlife Service, "Response to OTA Questionaire: Task Force on Water Resource Modeling," personal correspondence, October 1979.

U.S. Geological Survey

58. Appel, Charles A., and Bredehoeft, John D., "Status of Ground-Water Modeling in the U.S. Geological Survey," Geological Survey circular No. 737, 1976.
59. Baltzer, Bob, personal interview, August 1979.
60. Carrigan, Hadley, personal interview, August 1979.
61. Faust, Charles R. and Mercer, James W., "Finite-Difference Model of Two-Dimensional Single- and Two-Phase Heat Transport in a Porous Medium —version I," U.S. Geological Survey report 77-234, 1977.
62. Federal Interagency Work Group on Water Quality Data Needs for Small Watersheds, "Water Quality Data Needs for Small Watersheds: Surface Water Data, Draft," August 1978.
63. Grove, David B., "Ion Exchange Reactions Important in Groundwater Quality Models," symposium proceedings, Advances in Groundwater Hydrology, 1976.
64. Jackman, Alan P. and Yotshkura, Nobuhiro, "Thermal Loading of Natural Streams," U.S. Geological Survey professional paper 991, 1977.
65. Jennings, Marshall E. and Yotshkura, Nobuhiro, "Status of Surface-Water Modeling in the U.S. Geological Survey," Geological Survey circular No. 809, 1979.
66. Konikow, Leonard F., "Modeling Chloride Movement in the Alluvial Aquifer at the Rocky Mountain Arsenal, Colorado," U.S. Geological Survey water supply paper 2044, 1977.
67. Konikow, L. F. and Bredehoeft, J. D., "Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water," USGS book 7, ch. 2, 1978.

68. Konikow, Leonard F., and Bredehoeft, John D., "Modeling Flow and Chemical Quality Changes in an Irrigated Stream-Aquifer System," Water Resources Research, vol. 10, No. 3, June 1974.
69. Laird, L. B., "Response to OTA Questionaire: Task Force on Water Resource Modeling in the Federal Agencies," personal correspondence, October 1979.
70. Larson, Steve, personal interview, August 1979.
71. McKenzie, Stuart W., et al., "Steady-State Dissolved Oxygen Model of the Willamette River, Oregon," U.S. Geological Survey circular 715-J, 1979.
72. Plummer, L. Niel, et al., "WATEQF-A FORTRAN IV Version of WATER, A Computer Program for Calculating Chemical Equilibrium of Natural Waters," USGS, Water Resources Investigations 76-13, September 1976.
73. Trescott, Peter C., "Documentation of Finite-Difference Model for Simulation of Three-Dimensional Ground-Water Flow," U.S. Geological Survey report 75-438, September 1975.
74. Rickert, David A., and Hines, Walter G., "River Quality Assessment: Implications of a Prototype Project," *Science,* vol. 200, pp. 1113-1118, June 1978.
75. Trescott, Peter C., "Documentation of Finite-Difference Model for Simulation of Three-Dimensional Ground-Water Flow," U.S. Geological Survey report 75-438, September 1975.
76. Trescott, P.C., Pinder, G. F., and Larson, S. P., "Finite-Difference Model for Aquifer Simulation in Two Dimensions with Results of Numerical Experiments," ch. 1, book 7 of *Techniques of Water-Resources Investigations of the U.S. Geological Survey.*
77. U.S. Geological Survey, "Computer Programs for Modeling Flow and Water Quality of Surface Water Systems," September 1978.

Bureau of Reclamation

78. Bureau of Reclamation, "Response to OTA Questionnaire: Task Force on Water Resource Modeling," personal communication, November 1979.
79. Bureau of Reclamation, "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979; Bureau of Reclamation, Bureau of Reclamation Economic Assessment Model (BREAM) Technical Description, January 1978; Ribbens, Richard W., Technical Description of Return Flow Quality Simulation Model, Water and Power Resources Service, January 1980.

Independent Agencies

Council on Environmental Quality

80. Buffington, J. D., Milask, L. J., "An Overview of the UPGRADE Data Analysis System."
81. CEQ Executive Summary, response for OTA Water Resources Workshop.
82. CEQ, " 'Strawman' Responses to Objectives of the OTA Task Force on Water Resources Modeling," Oct. 24-25, 1979.

EPA: Office of Research and Development

83. Office of Research and Development, "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
84. Richardson, W. L., and Thomas, N. A., "A Review of EPA's Great Lakes Modeling Program," in *Proceedings of the EPA Conference on Environmental Modeling and Simulation,* W. R. Ott (ed.), report No., EPA-600/9-76-106 (Cincinnati, Ohio: Environmental Protection Agency, 1976).

EPA: Office of Toxic Substances

85. Wood, B., "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
86. Survey and Analysis Division, Office of Toxic Substances, "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
87. Zweig, G., "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.

EPA: Office of Water Planning and Standards

88. Athway, D., and Somers, P., staff, Urban Runoff Program, Implementation Branch, Water Planning Division, Office of Water Planning and Standards, EPA, personal interview, Aug. 17, 1979.
89. Cogger, B., "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
90. Dupuis, L., staff, Office of Analysis and Evaluation, Water Planning and Standards, EPA, personal interview, Aug. 17, 1979.

91. Ehreth, D., Callahan, M., Frederick, R., and Slimak, M., staff, Water Quality Analysis Branch, Monitoring and Data Support Division, Office of Water Planning and Standards, EPA, personal interview, Aug. 17, 1979.
92. Myers, C., staff, Implementation Branch, Water Planning Division, Office of Water Planning and Standards, EPA, personal interview, Aug. 17, 1979.
93. Office of Analysis and Evaluation, "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.
94. Stuart, T., Chief, Monitoring Branch, Office of Water Planning and Standards, EPA, personal interview, Aug. 17, 1979.
95. Swader, F., staff, Agricultural Runoff Program, Implementation Branch, Water Planning Division, Office of Water Planning and Standards, EPA, personal interview, Aug. 22, 1979.
96. Water Quality Analysis Branch, "Response to OTA Questionnaire: Task Force on Water Resource Modeling in Federal Agencies," personal correspondence, October 1979.

EPA: General References

97. Beckers, C. V., Parker, P. E., Marshall, R. N., and Chamberlain, S. G., "RECEIV-II, A Generalized Dynamic Planning Model for Water Quality Management," in *Proceedings of the EPA Conference on Environmental Modeling and Simulation,* W. R. Ott (ed.), report No. EPA-600/9-76-100 (Cincinnati, Ohio: Environmental Protection Agency, 1976).
98. Environmental Protection Agency, "A Statistical Method for the Assessment of Urban Stormwater," report No. EPA 440/3-79-023, prepared for Environmental Protection Agency, Washington, D.C., May 1979.
99. Falco, J. W., and Mulkey, L. A., "Modeling the Effect of Pesticide Loading on Riverine Ecosystems," in *Proceedings of the EPA Conference on Environmental Modeling and Simulation,* W. R. Ott (ed.), report No. EPA-600/9-76-106 (Cincinnati, Ohio: Environmental Protection Agency, 1976).
100. Leytham, K. M., and Johnson, R. C., "Watershed Erosion and Sediment Transport Model," Report No. EPA-600/3-79-028, prepared for Environmental Protection Agency, Athens, Ga., March 1979.
101. Pechan, E. H., and Luken, R. A., "Watershed Erosion and Sediment Transport Model," report No. EPA-600/3-79-028, prepared for Environmental Protection Agency, Athens, Ga., March 1976.
102. Taylor, P. L., "STORET: A Data Base for Models," in Workshop on Verification of Water Quality Models, report No. EPA-600/9-80-016, prepared for Environmental Protection Agency, Athens, Ga., April 1980.
103. True, H. A., "Planning Models for Non-Point Runoff Assessment," in *Proceedings of the EPA Conference on Environmental Modeling and Simulation,* W. R. Ott, (ed.), report No. EPA-600/9-76-106 (Cincinnati, Ohio: Environmental Protection Agency, 1976).
104. Versar, Inc., "Environmental Assessment of Priority Pollutants: A Review of Evaluative Models in Assessing the Fate of Pollutants, Final Report," contract No. 68-01-3852, prepared for Environmental Protection Agency, Washington, D.C. February 1979.

National Science Foundation

105. Ezra, A. A., "Executive Summary and 'Strawman' Responses to Objectives of the OTA Task Force on Water Resource Modeling," Oct. 24-25, 1979.

Water Resources Council

106. Walker, Lewis D., Water Supply Adequacy Analysis Model, for the OTA Task Force on Water Resource Modeling in the Federal Agencies, Oct. 24-25, 1979.

General References

107. Brandstetter, A. G., "Assessment of Mathematical Models for Storm and Combined Sewer Management," report No. EPA-600/2-76-175a, prepared for Environmental Protection Agency, Cincinnati, Ohio, August 1976.
108. Bugliarello, G., and Gunther, F. C., *Developments in Water Science I: Computer Systems and Water Resources* (New York: Elsevier Publishing Co., 1974).
109. Chung, Sang Chu, et al., *Computer Programs in Water Resources,* Minnesota University Water Resources Research Center, November 1977.
110. Grimsrud, G. Paul, et al., *Evaluation of Water Quality Models: A Management Guide for Planners* (Palo Alto, Calif.: Systems Control Inc., 1976).
111. Hinson, M.O., and Basta, D. J., "Analyzing Receiving Water Systems," in Analysis for Residuals

—Environmental Quality Management: Analyzing Natural Systems, Resources for the Future, D. J. Basta and B. T. Bower (eds.), Washington, D.C., prepared for the Office of Research and Development, Environmental Protection Agency, December 1979.

112. Horton, M. L., et al., *Analysis and Dissemination of Water Resources Information*, South Dakota State University Water Resources Institute, 1979.

113. Huber, W. C., and Heaney, J. P., "Analyzing Residuals Generation and Discharges From Urban and Nonurban Land Surfaces," in Analysis for Residuals—Environmental Quality Management: Analyzing Natural Systems, Resources for the Future, D. J. Basta and B. T. Bower (eds.), Washington, D.C., prepared for the Office of Research and Development, U.S. Environmental Protection Agency, December 1979.

114. Marks, David H., "Models in Water Resources," in A Guide to Models in Governmental Planning and Operations, EPA, August 1974.

115. U.S. Environmental Protection Agency, *Environmental Modeling and Simulation*, Washington, D.C., Office of Research and Development and Office of Planning and Management, EPA-600/9-76-016, 1976.

116. Viessman, W., Jr., Knapp, J. W., Lewis, G. L., and Harbaugh, T. E., *Introduction to Hydrology*, 2d ed. (New York: Harper & Row, 1977).

ATTACHMENT II.—SURVEY OF FEDERAL AGENCY MODEL USE RELATED TO MAJOR LEGISLATION

July 14, 1980

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D. C. 20510

OTA Survey of Model Use
in Major Federal Water
Resources Programs

Survey Instructions

The survey consists of two major parts: Part I, a Water Program Checklist; and Part II, Individual Program Questionnaires.

The Water Program Checklist provides information on model use in programs with which your office is actively involved. By involvement we mean any water resources programs your office has direct responsibility for or routinely deals with. Involvement includes program activities such as enforcement of regulations, compliance with regulations, operations and management, etc. A more complete list of activities appears on the Individual Program Questionnaire.

The Individual Program Questionnaire provides information on the purposes for which models are used in the program. Completing the Checklist will indicate which Questionnaires should be filled out.

Specific Instructions

Part I: Water Program Checklist

1. Column One - Program Involvement

   Check the boxes corresponding to programs with which your office is activity involved.

2. Column Two - Model Use

   Check the boxes corresponding to programs with which your office is actively involved and in which models are used. The term "model" refers to formal models, primarily mathematical models.

3. Last Row - Additional Programs

   Space is provided at the bottom of the Water Program Checklist to add any unlisted water resources programs with which your office is actively involved.

Part II: Individual Program Questionnaires

1. Individual Questionnaire (Limit Five)

   Complete one Questionnaire for each program that has both columns checked in Part I, the Water Program Checklist. If more than five programs qualify, choose the five water resources programs with which your office is most involved, and complete questionnaires for only those five programs.

2. Program Title and Legislative Authorization

   Fill in the program title at the top of each questionnaire. Provide the authorization if it is not on the Water Program Checklist or other than authorization listed.

3. Complete the Questionnaire(s)

   A partial example questionnaire is given below:

PROGRAM: Thermal discharges

Legislative Authorization - Public Law 95-217

Activity	Specific Purpose Models are Used	Relevant Section of Law, Rule, Regulation or Agency Guideline	Name of Model(s) or Generic Type
Enforce Regulations, Standards, Guidelines	Power Plant Siting	Section 316	temp. models USP and WRECEV

4. Additional Comments - Any additional comments may be written on the back of the Individual Program Questionnaires.

If you have any questions about the survey, please do not hesitate to call Robert Friedman, Project Director, at (202) 224-7031.

Please mail the completed Water Program Checklist and Individual Program Questionnaire(s) to:

Dr. Robert M. Friedman
Project Director
Office of Technology Assessment
U.S. Congress
Washington, D.C. 20510

PART I: WATER PROGRAM CHECKLIST

Column One Program Involvement	Column Two Model Use		Section
		FEDERAL WATER POLLUTION CONTROL ACT AMENDMENTS OF 1972 (AS AMENDED BY THE CLEAN WATER ACT OF 1977)	
☐	☐	Grants for pollution control programs	S. 106
☐	☐	Mine water pollution control programs	S. 107
☐	☐	Grants for construction of treatment works	S. 201
☐	☐	Areawide waste treatment management	S. 208
☐	☐	Basin planning	S. 209
☐	☐	Water quclity related effluent limitations	S. 302
☐	☐	Water quality standards and implementation plans	S. 303
☐	☐	Toxic and pretreatment effluent standards	S. 307
☐	☐	Oil and hazardous substances liability	S. 311
☐	☐	Clean lakes	S. 314
☐	☐	Thermal discharges and exemptions	S. 316
☐	☐	Guidelines...permits for dredged or fill material	S. 404
☐	☐	Disposal of sewage sludge	S. 405
		SAFE DRINKING WATER ACT	
☐	☐	Protection of underground sources of drinking water	S. 1421
☐	☐	Special study and demonstration project grants for waste water reuse, reclamation and recycling processes	S. 1444
		TOXIC SUBSTANCES CONTROL ACT	
☐	☐	Testing of chemical substances and mixtures	S. 4
☐	☐	Regulation of hazardous chemicals and mixtures	S. 6

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Column One Program Involvement	Column Two Model Use		Section
		RESOURCE CONSERVATION AND RECOVERY ACT	
[ ]	[ ]	Solid waste management guidelines	S. 1008
[ ]	[ ]	Identification and listing of hazardous wastes	S. 3001
[ ]	[ ]	Standards for owners and operators of hazardous waste treatment, storage and disposal facilities	S. 3004
[ ]	[ ]	Consolidated permits for hazardous waste management facilities	S. 3005
[ ]	[ ]	Grants for state resource recovery and conservation plans	S. 4008
[ ]	[ ]	Full scale demonstration facilities grants	S. 8004
[ ]	[ ]	Resource recovery systems and improved solid waste disposal facilities	S. 8006
		ENDANGERED SPECIES ACT	
[ ]	[ ]	Minimizations of impacts of Federal activities modifying critical habitats	S. 7
		SURFACE MINING CONTROL AND RECLAMATION ACT	
[ ]	[ ]	Surface coal mine reclamation permitting	S. 506
[ ]	[ ]	Environmental protection performance standards for surface coal mine reclamation	S. 515
		SOIL AND WATER RESOURCE CONSERVATION ACT OF 1977	
[ ]	[ ]	Data collection about soil, water and related resources	S. 5
[ ]	[ ]	Soil and water conservation programs	S. 6
		WATER RESOURCES PLANNING ACT	
[ ]	[ ]	Regional or river basin plans and programs and their relation to larger region requirements	S. 102
[ ]	[ ]	Coordinating Federal water and related land resources programs and policies	S. 102

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Column One Program Involvement	Column Two Model Use		Section
		COASTAL ZONE MANAGEMENT ACT	
[ ]	[ ]	State coastal zone land and water resources management program development and management grants	S. 305
		EXECUTIVE ORDER 11988	
[ ]	[ ]	Floodplain management	S. 2 & 3
		FLOOD CONTROL ACT OF 1936 AND AMENDMENTS	
[ ]	[ ]	Flood control structures	S. 1,2,3
		WATER RESOURCES DEVELOPMENT ACT OF 1974	
[ ]	[ ]	Nonstructural measures	S. 73
		FEDERAL RECLAMATION ACT OF 1902 AND AMENDMENTS	
[ ]	[ ]	Irrigation distribution systems	(43 U.S.C. 421)
[ ]	[ ]	Construction of small projects	(43 U.S.C. 422)
		OTHER ACT ______________________________	
[ ]	[ ]	Other Programs ______________________________	S.
[ ]	[ ]	______________________________	S.
[ ]	[ ]	______________________________	S.
		OTHER ACT ______________________________	
[ ]	[ ]	Other Programs ______________________________	S.
[ ]	[ ]	______________________________	S.
[ ]	[ ]	______________________________	S.

PART II: INDIVIDUAL PROGRAM QUESTIONNAIRE

PROGRAM ______________________________
(fill in only one program on each Questionnaire)

Legislative authorization ________________
(if not on OTA program list or other than authorization listed on Water Program Checklist)

Respondent ______________________
Office ______________________
Agency ______________________
Phone Number ______________________

Activities	Specific Purposes for which Models are Used	Relevant Section of Law, Rule, Regulation or Agency Guideline	Name of Model(s) or Generic Type
Program Planning and Scope			
Promulgate Regulations, Set Standards, Develop Guidelines			
Enforce Regulations, Standards, Guidelines			
Comply with Regulations, Standards, Guidelines			
Plan or Evaluate Projects, Activities			
Allocate Planning or Construction Funds			
State or Local Advisory Assistance			
Operation and Management			
Other Program Activities			

Appendix C
Summaries of Related Modeling Studies

This appendix summarizes five previously completed studies of model development, use, and dissemination—three conducted wholly within the United States, one from Canada, and one international assessment. The five were chosen for their currency and relevance to the issues raised in this report, and largely corroborate OTA findings regarding current modeling issues. They are:

1. "Federally-Supported Mathematical Models: Survey and Analysis," National Science Foundation (NSF), 1974.
2. "Ways to Improve Management of Federally-Funded Computerized Models," General Accounting Office (GAO), 1976.
3. "A Study for Assessing Ways to Improve the Utility of Large-Scale Models," National Bureau of Standards (NBS), 1978.
4. "Survey of Environmental Management Simulation Models in Canada," R. D. Miller.
5. "SCOPE International Assessment Project on Groundwater Model Modeling"

1. "Federally-Supported Mathematical Models: Survey and Analysis" (Fromm, Hamilton, & Hamilton)

This survey was completed in 1974 by NSF. It surveyed a universe of over 650 models which addressed some aspect of social decisionmaking, and which were used by or developed for nondefense Federal agencies. Responses were received for 222 models, from over 230 project directors and 80 Federal agency monitors.

Respondents indicated that the most important constraints limiting model utility were: 1) data availability, and 2) ease of use by nontechnicians. Responses also indicated a prevailing tendency for actual use of models to fall short of intended use. Policy-related model uses appeared to have the greatest shortfall—between one-third and two-thirds of the models failed to achieve their stated purposes with respect to direct application to policy problems.

Based on survey responses, staff attributed low policy utilization rates for models primarily to lack of communication between model builders and potential policymakers during model development, and secondarily to policymakers' limited capabilities to use models once they had been developed. The study found very little interaction between developers and users during model development—actual briefings were held in only 19 percent of the projects, and user agencies ran models and analyzed results in only 34 percent; written reports alone were provided in over 50 percent of surveyed modeling projects. Most of the projects were supported by grants, with very infrequent specification of performance requirements or desired detail and characteristics by the funding agency.

The survey identified two dimensions to the "ease of use" problem: 1) decisionmaker understanding of models, and 2) the adequacy of developer-supplied instructions for operating the model. Both developers and agency personnel noted that policymakers frequently lack the training that would equip them to use models appropriately. On the other hand, in about 75 percent of the surveyed cases, the documentation supplied by the developer was considered inadequate to enable non-project personnel to set up and run the model. The majority of the documentation efforts failed to include user manuals, operating instructions, or computer programs. Use rates were found to be highest for models having user manuals; these tended to be produced when funding agencies specified desired model characteristics, and when funding was carried out under contracts rather than grants.

2. "Ways to Improve Management of Federally-Funded Computerized Models"

This 1976 survey conducted by GAO was based on responses to questionnaires regarding 519 federally funded models developed and/or used in the U.S. Pacific Northwest. Fifty-seven of those models costing over $100,000 to develop were selected for detailed review—and 33 of these were described by respondents as having encountered "major problems" in development. GAO characterized these problems as being due to:

- inadequate management planning (70 percent);
- inadequate management commitment (15 percent); and
- inadequate management coordination (15 percent).

GAO found that model development problems tended to result in models not being used once they are developed, cost overruns for models, and prolonged development time. The reasons most frequently given for model development problems were: 1) the unreliability of model results, 2) developers' inability to obtain necessary data, and 3) users' failure to allocate enough funds to complete the model. GAO further outlined development problems stemming from deficiencies in management planning, commitment, and coordination:

- Problems attributable to inadequate management planning:

  - Management did not clearly define the problem to be modeled; thus, the developer had to guess what had to be modeled.
  - The developer was not able to obtain the data needed to make the model function.
  - Management allocated insufficient funds to complete the model.
  - Management did not make workable provisions for updating the model for future use; thus, the model soon began to produce outdated information.
  - Management did not make provisions for evaluating the model.
  - Management did not clarify documentation requirements for the model. As a result, only the developer understood how it worked and the relationship maintained by the variables incorporated into it.
- Problems attributable to inadequate management commitment:
  - Management did not actively participate in planning of the model. Thus, the model did not clearly reflect their needs.
  - Management did not understand computer modeling techniques and applications. Consequently, they could not effectively use information obtained from the models.
- Problems attributable to inadequate management coordination:
  - Management did not monitor the model development effort on a continuous basis. Thus, management allowed development efforts to continue after they should have been terminated.
  - Managers did not coordinate the development effort with the developer. As a result, the model was developed without reasonable assurance that it would meet user needs.

Two major solutions for these problems were proposed in the GAO report: First, the use of a phased approach to model development, requiring the funding agency to review projects and decide whether to continue development at the end of each of five stages: 1) problem definition, 2) preliminary design, 3) detail design, 4) evaluation, and 5) maintenance. This suggested procedure is seen as promoting a more thorough early investigation of the nature of the problem and of possible solution methods, as well as providing a method of controlling commitments to modeling efforts.

GAO's second proposal was that the Department of Commerce and the General Services Administration, using their respective authorities under the Brooks Act (Public Law 89-306), formulate Government-wide standards and guidance on developing and procuring computerized models, and coordinate with other Federal agencies to obtain advice regarding such standards and guidance.

3. “A Study for Assessing Ways to Improve the Utility of Large-Scale Models”
(S. I. Gass, Z. F. Landsdowne, R. P. Harvey, and A. J. Lemonine)

This study, completed in December 1978 for NBS, surveyed a group of modelers selected for their recognized expertise and their interest in the modeling profession. Of 57 modelers who were requested to participate, 39 responded, yielding the following cross-section of affiliations and expertise:

Affiliation		*Expertise*	
University	8	Analytic	19
Not-for-profit	8	Simulation	12
Profit	9	Economics	9
Government	14		
Total	39	Total	39

These participants, responding to propositions and statements in 18 model improvement area categories, gave highest priority to proposals to clarify the relationship between model developer and user, and increase the interaction between them. Strongest support was voiced for such specific proposals as:

1. Model developers should specify a documentation plan in their contract, detailing the documents to be produced, the resources allocated, and personnel responsibilities.
2. The Federal Government should establish a flexible set of model documentation guidelines that can be used by model developers and sponsors to create a project's documentation plan.
3. Requests for proposals (RFPs) should indicate the ultimate user of the model, and require meetings between model developers and users to aid in designing models to meet user requirements.
4. Model developers should be required to prepare verification and validation test plans, report results of the tests, and describe their implications for future use of their models.
5. Model forums should be established by professional organizations, industrial groups, and the Federal Government.

Participants also indicated strong support for coordinated model development and data collection. They supported mandatory data availability and costing assessments prior to the issuance of an RFP for a model, and requirements for parallel data collection efforts to be specified in the “scope of work” if necessary data are not already available.

Moderate support was also expressed for: 1) requiring greater specificity in the RFP statement of work, including explicit statements of model scope and objectives; 2) Federal exploration of phased management approaches to model development; and 3) requiring all model development contracts to address the issue of user training.

Participants strongly disapproved of centralized Government-sponsored review and analysis relating to models, specifically rejecting model clearinghouses; a model testing, verification, and validation center; and a Government modeling research center.

4. "Survey of Environmental Management Simulation Models in Canada"

(R. D. Miller)

Simulation modelers in Canada who were involved with developing environmental management models were requested to complete questionnaires regarding the models they had developed. Questions were directed toward five general areas:

1. purpose of the model, including the audience to which it was directed;
2. degree of success, including implementation of the model and its use in decisionmaking;
3. problems encountered during model development and implementation;
4. planning and managerial factors that might serve as predictors of success; and
5. technical details of how the simulation was carried out.

The overall results of the survey suggest that the surveyed model development projects suffered from lack of involvement and meaningful contribution by decisionmakers in the early stages of model development. A lack of user credibility accorded to the model was reported only in cases where users had not been involved in managing the project. In these cases, user credibility was cited as a problem with far greater frequency than the modeler's willingness to help, suggesting that modelers neglect to involve decisionmakers more often than decisionmakers refuse to consider the advantages of developing models.

Specific correlations were found between:

- perceived success and attempts to involve users at early stages of development, specifically by giving system managers some voice in managing the simulation project;
- perceived success and preproject literature searches or state-of-the-art surveys;
- perceived success and intended audience. Cases where model output was to be used by technical or research staff had a significantly better success level than cases where model results were to be used by policy formulation groups, or middle- or high-level management; and
- model purpose and difficulties encountered during the project. Where models were constructed primarily for research purposes, lack of understanding of mechanisms, and lack of available data, were most often cited as problems; where models were intended for policy recommendations, lack of user credibility was the most frequently named problem.

5. "SCOPE International Assessment Project on Groundwater Model Modeling"

The SCOPE project was carried out between 1975 and 1977, primarily through surveys of two groups: 1) active model developers, and 2) those active in applying models to management problems. Reports on approximately 250 models were submitted in response to the project survey.

The purpose of the assessment was to provide guidance on measures for improving the utility of models in ground water management. Four major problem areas were identified during the course of the project, and were ranked by project staff and an international steering committee in the following order of importance:

1. accessibility of models to users;
2. communications between managers and technical personnel;
3. inadequacies of data; and
4. inadequacies of modeling.

The survey found difficulties in gaining access to existing models to be the most serious impediment to effective use of models in ground water management. Major problems of accessibility revolve around the usability of model documentation, model distribution, adequate training in the use of models, and user certification. Project staff suggested that improvements in these areas would require shifts in the incentive structures of institutions, or even modifications to the institutions themselves. Their primary recommendation involved establishing public agency requirements for adequate documentation as a prerequisite for funding any model development effort.

To improve communication between managers and technical personnel, the study staff recommended measures to increase interactive participation in problem definition and model application, so that managers become directly involved in developing the models they commission. Additional recommendations included designing model outputs to be easily understandable by nontechnical personnel, and encouraging further development of management "decisionmaking" models.

Data-gathering recommendations stressed improved methods for routine data collection, storage, and retrieval, and sensitivity analysis as a method of determining the most critical data needs for modeling purposes.

Appendix D

Additional References to Models and Modeling Studies

Surface Water Flow and Supply References

Table of Model Types (with reference numbers)

General (50, 54, 66, 75, 82, 86, 112)
1. Watershed Soil/Water Process Models (5, 7, 9, 16, 18, 19, 23, 40, 41, 43, 53, 57, 59, 61, 88, 91, 95, 97, 98, 104, 108, 116, 117, 118, 119)
2. Snow Accumulation and Melt Models (1, 2, 3, 9, 16, 23, 40, 41, 43, 53, 59, 61, 98, 106, 118, 119)
3. Baseflow Models (5, 7, 9, 16, 19, 23, 34, 40, 41, 43, 52, 53, 57, 59, 61, 88, 98, 117, 118, 119)
4. Channel Routing Models (5, 9, 16, 18, 19, 28, 40, 41, 43, 47, 74, 91, 95, 97, 98, 104, 108, 119)
5. Lake and Reservoir Routing Models (19, 43, 47, 57, 97, 98)
6. Flood Formulae (24, 32, 37, 39, 62, 73, 80, 93, 108)
7. Regional Flood Equations (24, 26, 48, 62, 64, 73, 87, 92, 115)
8. Regional Flood Simulation Models (24, 45, 62, 65, 125)
9. Flow Frequency Models (73, 78, 85)
10. Evapotranspiration Models (5, 9, 16, 18, 19, 23, 31, 40, 41, 43, 53, 57, 58, 59, 60, 61, 76, 77, 83, 91, 96, 97, 98, 107, 116, 117, 118, 119)
11. Unit Hydrograph Models (22, 24, 39, 62, 94, 108)
12. Dam Failure Models (5, 10, 44)
13. Reservoir Water Accounting Models (9, 57, 98)
14. Annual Data Generation Models (27, 67, 68, 69, 79)
15. Regional Data Generation Models (20, 26, 36, 51, 64, 70, 79, 87, 111)
16. Reservoir Sedimentation Models (8, 15, 57, 98)
17. Ice Formation and Breakup Models (21, 25, 33, 71, 72, 81, 89, 102, 103, 120)
18. Freezing and Breakup Formulae (12, 21, 25, 33, 72, 81, 89, 102, 103, 120)
19. Plot Size Soil/Water Process Models (29, 31, 53, 57, 58, 59, 60, 61, 88, 95, 96, 108)
20. Plot Snow Accumulation and Melt Models (31, 53, 59, 60, 61, 96)
21. Bank Sloughing Models (109)
22. Flood Inundation Models (46)
23. Channel Erosion and Deposition Models (4, 84, 90, 101, 105)
24. Channel Geometry Equations (63, 99)
25. Irrigation Water Demand Models (57, 100)
26. Land Drainage Models (49, 57, 110, 114)
27. Conduit Capacity Models (11)
28. Pipe Network Models (56, 113)
29. Regional Water Use Relationships (30, 42)
30. Annual Use Generation Models (17)
31. Plant Water Use Models (6, 13, 14, 35, 38, 55, 76, 77, 83, 107)
32. System Water Need Models (56)

References

1. Anderson, E. A., "The Synthesis of Continuous Snowmelt Runoff Hydrographs on a Digital Computer," technical report 36, Department of Civil Engineering, Stanford University, Stanford, Calif., 1964.
2. ———, "National Weather Service River Forecast System: Snow Accumulation and Ablation Model," NOAA technical memorandum, NWS HYDRO-17, Department of Commerce, Silver Spring, Md., 1973.
3. ———, "A Joint Energy and Mass Balance Model of a Snow Cover," NOAA technical report, NWS 19, Department of Commerce, Silver Spring, Md., 1976.
4. Beer, C. E., and Johnson, H. P., "Factors Related to Gully Growth in the Deep Loess Area of Western Iowa," Department of Agriculture, miscellaneous publication 970, 1965, pp. 37-43.
5. Betson, R. P., "A Continuous Daily Streamflow Model," TVA research paper No. 8, Knoxville, Tenn., 1972.
6. Blaney, H. F., and Griddle, W. D., "Determining Water Requirements in Irrigated Areas From Climatological and Irrigation Data," Department of Agriculture, Soil Conservation Service, TP-96, 1950.
7. Bowles, D. S., and Riley, J. P., "Low Flow Modeling in Small Steep Watersheds," *Journal of the Hydraulics Division,* proceedings of ASCE 102(HY9):1225-1239, 1976.
8. Brune, G. M., "Trap Efficiency of Reservoirs," Transactions of the American Geophysical Union, 34(3):407-418, 1953.
9. Burnash, R. J. C., Ferrall, R. L., and McGuire, R. A., "A Generalized Streamflow Simulation

System: Conceptual Modeling for Digital Computers," unnumbered publication, California Department of Water Resources, 1973.

10. Chen, C-L, and Armbruster, J. T., *Dam-Break Wave Model: Formulation and Verification,* proceedings of ASCE, 106(HY5):747-768, 1980.
11. Chow, V. T., *Open Channel Hydraulics* (New York: McGraw-Hill, 1959).
12. ______, *Handbook of Applied Hydrology* (New York: McGraw-Hill, 1964).
13. Christensen, J. E., "Pan Evaporation and Evapotranspiration From Climatic Data," proceedings of ASCE, 94(IR2):243.265, 1968.
14. Christensen, J. E., and Hargreaves, G. H., "Irrigation Requirements From Evaporation," International Commission on Irrigation and Drainage, Seventh Congress, 25.569-23.596, 1970.
15. Churchill, M. A., "Discussion of 'Analysis and Use of Reservoir Sedimentation Data,' by L. C. Gottschalk," proceedings of the *Federal Interagency Sedimentation Conference,* Denver, Colo., 1945, pp. 139-140 (published by Department of the Interior, Bureau of Reclamation, Denver).
16. Crawford, N. H., and Linsley, R. K., "Digital Simulation in Hydrology: Stanford Watershed Model IV," technical report 39, Department of Civil Engineering, Stanford University, Stanford, Calif., 1966.
17. Cruz, S-L, and Yevjevich, V., "Stochastic Structure of Water Use Time Series," Colorado State University hydrology paper No. 52, 1972.
18. Dawdy, D. R., Lichty, R. W., and Bergman, J. M., "A Rainfall-Runoff Simulation Model for Estimation of Flood Peaks for Small Drainage Basins," U.S. Geological Survey professional paper 506-6 (Washington, D.C.: U.S. Government Printing Office, 1972).
19. Dawdy, D. R., Schaake, Jr., J. C., and Alley, W. M., "Distributed Routing Rainfall-Runoff Model," U.S. Geological Survey Water Resources Investigations 78-90, 1978.
20. DeWalle, D. R., and Rango, A., "Water Resources Applications of Stream Channel Characteristics on Small Forested Basins," Water Resources Investigations 78-90, 1972.
21. Dilley, J. F., "Lake Ontario Ice Modeling," IFYGL Phase 3, General Electric Co., Philadelphia, Pa., NTIS PB-264 998, 1976.
22. Dooge,, J. C. I., "Linear Theory of Hydrologic Systems," Department of Agriculture Technical Bulletin 1468 (Washington, D.C.: U.S. Government Printing Office, 1973).
23. Eggleston, K. O., Israelsen, E. K., and Riley, J. P., "Hybrid Computer Simulation of the Accumulation and Melt Process in a Snowpack," Utah Water Research Laboratory Publication PRWG65-1, 1971.
24. Eychaner, J. H., "Estimating Runoff Volumes and Flood Hydrographs in the Colorado River Basin, Southern Utah," U.S. Geological Survey Water Resources Investigations 76-102, 1976.
25. Ficke, E. R., and Ficke, J. F., "Ice on Rivers and Lakes: A Bibliographic Essay," U.S. Geological, Survey Water Resources Investigations, 1977.
26. Fields, F. K., "Estimating Streamflow Characteristics for Streams in Utah Using Selected Channel-Geometry Parameters," U.S. Geological Survey Water Resources Investigations 34-71, NTIS PB-241 541, 1975.
27. Fiering, M. B., and Jackson, B. B., *Synthetic Streamflows,* Water Resources Monograph 1, American Geophysical Union, Washington, D.C., 1971.
28. Fread, D. L., "Technique for Implicit Dynamic Routing in Rivers and Tributaries," Water Resources Research 9(4):918-926, 1973.
29. Gifford, G. F., and Hawkins, R. H., "Deterministic Hydrologic Modeling of Grazing System Impacts on Infiltration Rates," Water Resources Bulletin 15(4):924-934, 1979.
30. Gleason, G. B., "Consumptive Use in Municipal and Industrial Areas," proceedings of ASCE 77, separate No. 99, 1951.
31. Goldstein, R. A., Mankin, J. B., and Luxmore, R. J., "Documentation of PROSPER: A Model of Atmosphere-Soil-Plant Water Flow," EDFB-IBP-73-9, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1974.
32. Grunsky, C. E., "Rain and Runoff Near San Francisco, California," transactions of ASCE, 1090, 1908.
33. H. G. Acres, Ltd, "Review of Current Ice Technology and Evaluation of Research Priorities," report to Inland Waters Branch, 105, Environment Canada, 1971.
34. Hall, F. R., "Base-Flow Recessions: A Review. Water Resources Research," 4(5):973-983, 1968.
35. Hargreaves, G. H., "Consumptive Use Derived From Evaporation Pan Data," proceedings of ASCE, 94(IR1):97-105, 1968.
36. Hedman, E. R., "Mean Annual Runoff as Related to Channel Geometry of Selected Streams in California," U.S. Geological Survey Water Supply report 1999-E (Washington, D.C.: U.S. Government Printing Office, 1970).
37. Helvey, J. D., "Interception by Eastern White Pine," Water Resources Research, 3(3):723-729, 1967.

38. Hendricks, D. W., and Hansen, V. E., "Mechanics of Evapotranspiration," transactions of ASCE, 128 (III):422-443, 1962.
39. Hewlett, J. D., Cunningham, G. B., and Troendle, C. A., "Predicting Stormflow and Peakflow From Small Basins in Humid Areas by the R-Index Method," Water Resources Bulletin, 13(2): 231-253, 1977.
40. Holtan, H. N., and Lopez, N. C., "USDAHL-70 Model of Watershed Hydrology," U.S. Department of Agriculture Technical Bulletin 1435, 1971.
41. ______, "USDAHL-73 Revised Model of Watershed Hydrology," Department of Agriculture Plant Physiological Institute report 1, 1973.
42. Hughes, T. C., and Gross, R., "Domestic Water Demand in Utah." Utah Water Research Laboratory report UWRL/P-79/04, 1979.
43. Hydrocomp, Inc., "Hydrocomp Simulation Programing Operations Manual," Hydrocomp, Inc., Palo Alto, Calif., 1969.
44. ______, "FULEQ, Full Equations Hydraulics Dam Failure," Palo Alto, Calif., 1976.
45. ______, "Planning and Modeling in Urban Water Management," Palo Alto, Calif., 1978.
46. Hydrologic Engineering Center, "HEC-2, Water Surface Profiles: User's Manual," U.S. Army Corps of Engineers, Davis, Calif., 1972.
47. ______, "HEC-5c, Reservoir System Operation for Flood Control and Conservation," U.S. Army Corps of Engineers, Davis, Calif., 1975.
48. Hydrology Committee, Water Resources Council, "Guidelines for Determining Flood Flow Frequency," bulletin 17, 1976.
49. International Institute for Land Reclamation and Improvement, *Drainage Principles and Applications,* publication No. 16, 4 vols., Wajeninen, Netherlands, 1972.
50. James, D. E. (ed.), *U.S. National Report to the IUGG,* American Geophysical Union, Washington, D.C., 1979.
51 James, L. D., Bowles, D. S., James, W. R., and Canfield, R. V., *Estimation of Water Surface Elevation Probabilities and Associated Damages for the Great Salt Lake,* Utah Water Research Laboratory publication UWRL/P-79/03, 1979.
52. James, L. D., and Thompson, W. O., "Least Squares Estimation of Constants in a Linear Recession Model," Water Resources Research, 6(4): 1062-1069, 1970.
53. Jaynes, R. A., "A Hydrologic Model of Aspen-Conifer Succession in the Western United States." Department of Agriculture Forest Service research paper INT213, 1978.
54. Jennings, M. E., and Yotsukura, N., "Status of Surface-Water Modeling in the U.S. Geological Survey," U.S. Geological Survey circular 809, 1979.
55. Jenson, M. E., and Haise, H. R., "Estimating Evapotranspiration From Solar Radiation," proceedings of ASCE, 89(IR4):15-41, 1963.
56. Jeppson, R. W., *Analysis of Flows in Pipe Networks,* Ann Arbor Science, 1976.
57. Knisel, W. G. (ed.), *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems,* Department of Agriculture Conservation Research Report 26, 1980.
58. Larson, N. M., and Reeves, M., "Analytic Analysis of Soil-Moisture and Trace Contaminant Transport," Oak Ridge National Laboratory report ORNL/NSF/EATC-12, undated.
59. Leaf, C. F., and Alexander, R. R., "Simulating Timber Yields and Hydrologic Impacts Resulting From Timber Harvest on Subalpine Watersheds," 1975.
60. Leaf, C. F., and Brink, G. E., "Computer Simulation of Snowmelt Within a Colorado Subalpine Watershed," Department of Agriculture Forest Service research paper RM-99, 1973.
61. ______, "Hydrologic Simulation Model of Colorado Subalpine Forest," Department of Agriculture Forest Service research paper RM-107, 1973.
62. Lee, B. H., Reich, B. M., Rachford, T. M., and Aron, G., "Flood Hydrograph Synthesis for Rural Pennsylvania Watersheds," Department of Civil Engineering, Pennsylvania State University, 1974.
63. Leopold, L. B., and Maddock, T. G., "The Hydraulic Geometry of Stream Channels and Some Physiographic Implications," U.S. Geological Survey professional paper 252, 1953.
64. Lowham, H. W., "Techniques for Estimating Flow Characteristics of Wyoming Streams," U.S. Geological Survey Water Resources Investigations 76-112, 1976.
65. Lumb, A. M., and James, L. D., "Runoff Files for Flood Hydrograph Simulation," proceedings of ASCE, 102 (HY10):1515-1531, 1976.
66. McCuen, R. H., Rawls, W. J., Fisher, G. T., and Powell, R. L., "Flood Flow Frequency for Ungaged Watersheds: A Literature Evaluation," Department of Agriculture, Agriculture Research Service, ARS-NE-86, 1977.
67. Mandelbrat, B. B., "A Fast Fractional Gaussian Noise Generator," Water Resources Research, 7(3):543-553, 1971.
68. ______, "Broken Line Process Defined as an Approximation to Fractional Noise," Water Resources Research, 8(5):1354-1356, 1972.
69. Mejia, J. M., Rodriguez-Itunbe, I., and Dawdy, D. R., "Streamflow Simulation 2: The Broken

Line Process as a Potential Model for Hydrologic Simulation," Water Resources Research, 8(4): 931-941, 1972.

70. Mejia, J. M., and Rousselle, J., "Disaggregation Models in Hydrology Revisited," Water Resources Research, 12(2):185-186, 1976.
71. Muller, A., "Frazil Ice Formation in Turbulent Flow," report No. 214, Iowa Institute of Hydraulic Research, Iowa City, Iowa, 1978.
72. Muller, A., and Calkins, D. J., "Frazil Ice Formation in Turbulent Flow," proceedings of IAHR Symposium on Ice Problems, Lulea, Sweden, vol. II: 219-234, 1978.
73. National Environmental Research Council, *Flood Studies Report, Volume I: Hydrological Studies,* London, England, 1975.
74. ———, *Flood Studies Report. Volume II; Flood Routing Studies,* London, England, 1975.
75. Nieber, J. L., Walter, M. F., and Black, R. D., "A Review and Analysis of Selected Hydrologic Modeling Concepts," OWRT completion report, project No. A-061-NY, 1975.
76. Nimah, M. N., and Hanks, R. J., "Model for Estimating Soil, Water, Plant, and Atmospheric Interrelations, 1: Description and Sensitivity," proceedings of SSSA, 37:522-527, 1973a.
77. ———, "Model for Estimating Soil, Water, Plant, and Atmospheric Interrelations, 2: Field Test of Model," proceedings of SSSA, 37:528-532, 1973b.
78. North, M., "Time Dependent Stochastic Model of Floods," proceedings of ASCE, 106(HY5):649-665, 1980.
79. O'Connell, P. E., "Stochastic Modeling of Long-Term Persistence in Streamflow Sequences," internal report, Hydrology Section, Civil Engineering Department, Imperial College, London, 1974.
80. Ol' deKop, E. M., "On Evaporation From the Surface of River Basins," Tr. IUr'ev Obs. Leningrad, 1911 (cited in Sellars, 1965).
81. Osterkamp, T. E., "Frazil Ice Formation: A Review," proceedings of ASCE, 104(HY9):1239-1256, 1978.
82. Peck, E. L., Bochin, N. A., Kouzel, A., Lennox, D. H., and Sundblad, B. (eds.), *State of the Art in Transposable Watershed Models,* proceedings of Third Northern Research Basin Symposium Workshop, International Hydrological Program, Quebec City, 1979.
83. Penman, H. L., "Natural Evaporation From Open Water, Bare Soil, and Grass," proceedings of Royal Society of London, Series A 193:120-145, 1948.
84. Pfankuch, D. J., "Stream Reach Inventory and Channel Stability Evaluation," Department of Agriculture Forest Service, Region 1, Missoula, Mont., 1975.
85. Rao, D. V., "Log Pearson Type 3 Distribution: A Generalized Evaluation," proceedings of ASCE, 106(HY5):853-872, 1980.
86. Renard, K. G., Rawls, W. J., and Fogel, M. M., "Currently Available Models," ch. 13 in *Hydrologic Modeling of Small Watersheds,* ASAE monograph, St. Joseph, Mich., 1980.
87. Riggs, H. C., "Streamflow Characteristics From Channel Size," proceedings of ASCE, 104(HY1): 87-96, 1978.
88. Riley, J. P., and Hawkins, R. H., "Hydrologic Modeling of Rangeland Watersheds," in *Watershed Management on Range and Forest Lands,* proceedings of the Fifth Workshop of the United States/Australia Rangelands Panel, Boise, Idaho, published by Utah Water Research Laboratory, 1975.
89. Rogers, J. C., "Evaluation of Techniques for Long Range Forecasting of Air Temperature and Ice Formation," NOAA technical memorandum ERL GLERL-8, 1976.
90. Rosgen, D. F., "Mass Wasting," ch. III in *WRENS: U.S. Forest Service Report to EPA,* agreement EPA-IAG-D6-0060, Review Draft.
91. Ross, B. B., Shanholtz, V. O., Contractor, D. N., and Carr, J. C., "A Model for Evaluating the Effect of Land Uses on Flood Flows," bulletin 85, Virginia Water Resources Research Center, 1975.
92. Saah, A. D., et al., "Development of Regional Regression Equations for Solution of Certain Hydrologic Problems in and Adjacent to Santa Clara County," Santa Clara Valley Water District, San Jose, Calif., 1976.
93. Sellars, W. D., *Physical Climatology,* University of Chicago Press, 1965.
94. Sherman, L. K., "Stream-Flow From Rainfall by the Unit-Graph Method," *Engineering News-Record,* 108:501-505, 1932.
95. Simons, D. B., Li, R. M., and Stevens, M. A., "Development of a Model for Predicting Water and Sediment Yield From Storms on Small Watersheds," Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz., 1975.
96. Solomon, R. M., Ffolliott, P. F., Baker, Jr., M. B., and Thompson, J. R., "Computer Simulation of Snowmelt," Department of Agriculture Forest Service research paper RM-174, 1976.
97. Spencer, D. W., and Alexander, T. W., "Technique for Estimating the Magnitude and Frequency of Floods in St. Louis County, Missouri," U.S. Geological Survey Water Resources Investigations 78-139, 1978.

98. Staff, Hydrologic Research Laboratory, "National Weather Service River Forecast System, Forecast Procedures," NOAA technical memorandum NWS HYDRO-14 and HYDRO-17, Department of Commerce, Silver Spring, Md., 1972.
99. Stall, J. B., and Fok, Y. S., "Hydraulic Geometry of Illinois Streams," University of Illinois Water Resources Center research report 15, 1968.
100. Stewart, J. I., et al., "Optimizing Crop Production Through Control of Water and Salinity Levels in the Soil," Utah Water Research Laboratory publication PRWG151-1, 1977.
101. Swanson, J. F., and Swanston, D. N., "A Conceptual Model of Solid Mass Movement Surface Soil Erosion and Stream Channel Erosion Processes," Coniferous Forest Biome Erosion Modeling Group, biome report No. 72, 1973.
102. Tatinclaux, J. C., "Equilibrium Thickness of Ice Jams," proceedings of ASCE, 103(HY9):959-974, 1977.
103. ——, "River Ice Jam Models." proceedings of IAHR Symposium on Ice Problems, Luela, Sweden, vol. II:449-460, 1978.
104. Terstriep, M. L., and Stall, J. B., "The Illinois Drainage Area Simulator, ILLUDAS," Illinois State Water Survey bulletin 58, 1974.
105. Thompson, J. R., "Quantitative Effects of Watershed Variances on the Rate of Gully Head Advancement," transactions of ASAE, 7(1):54-55, 1964.
106. Thomsen, A. G., and Striffler, W. D., "Hydrograph Simulation With Spatially Distributed Input," presented at the American Geophysical Union fall meeting, San Francisco, Calif., 1979.
107. Thornthwaite, C. W., "An Approach Toward a Rational Classification of Climate," *Geographical Review,* 38(1):55-94, 1948.
108. USDA, Soil Conservation Service, *National Engineering Handbook,* sec. 4, "Hydrology" (Washington, D.C.: U.S. Government Printing Office, 1972).
109. USDI, Bureau of Reclamation, "Design of Small Dams," A Water Resources Technical Publication, secs. 135 to 139 (Washington, D.C.: U.S. Government Printing Office, 1977).
110. ——, "A Guide to Integrated Plant, Soil and Water Relationships for Drainage of Irrigated Lands," *Drainage Manual,* Washington, D.C., 1978.
111. Valencia, D., and Schaake, Jr., J. C., "Disaggregation Processes in Stochastic Hydrology," Water Resources Research, 9(3):580-585, 1973.
112. Van Haveren, B. P., and Leaveslen, G. H., "Hydrologic Modeling of Coal Lands," Department of Interior, Bureau of Land Management, Denver, Colo., 1979.
113. Wake, A., and Rumer, R. R., "Development of a Thermodynamic Model for Ice Regime in Lake Erie," proceedings of IAHR Symposium on Ice Problems, Luela, Sweden, vol. II:143-162, 1978.
114. Walker, W. R., "Identification and Initial Evaluation of Irrigation Return Flow Models," Irrigation Hydrology Co., Fort Collins, Colo., 1978.
115. Watt, W. E., "A Relation Between Peak Discharge and Maximum 24-Hour Flow for Rainfall Floods," *Journal of Hydrology,* 14:285-292, 1971.
116. Williams, J. R., and LaSeur, W. V., "Water Yield Model Using SCS Curve Numbers," proceedings of ASCE, 102(HY9):1241-1254, 1976.
117. Wilson, T. V., and Ligon, J. T., "Prediction of Baseflow for Piedmont Watersheds," technical report 80, Clemson University Water Resources Research Institute, 1979.
118. Woodward, D. E., "Hydrologic and Watershed Modeling for Watershed Planning," transactions of ASAE, 99(3):582-584, 1973.
119. World Meteorological Organization, "Intercomparison of Conceptual Models Used in Operational Hydrological Forecasting," WMO No. 429, Geneva, 1975.
120. Yen, B. C., and Pansic, N., "Surcharge of Sewer Systems," Illinois Water Resources Center research report 149, 1980.

Surface Water Quality Model References

The following tables and figures are from:

D. J. Basta and B. T. Bower (eds.), *Analysis for Regional Residuals—Environmental Quality Management: Analyzing Natural Systems,* Resources for the Future Research Paper (Baltimore, Md.: Johns Hopkins University Press for Resources for the Future, 1982).

Figure D-1 displays 14 of the most widely used surface water runoff models, and the types of problems each model is capable of analyzing. The following table (table D-1) lists and identifies the originator of over 40 surface water runoff models, including the 14 from figure D-1. Table D-1 is organized by the following categories: screening procedures, simplified computer models, continuous simulation models, and single event simulation models. The table includes those models that have received most extensive use (both private and governmental models) and less widely used models developed by governmental agencies.

Figure D-2 displays 27 of the most widely used receiving water quality models and the types of water bodies and problems they address. Again, table D-2 follows with a more extensive list of models, concentrating on those most widely used and/or developed by a Government agency.

FIGURE D-1
Characteristics of Selected Surface Water Runoff Models

MODEL NAME	PROBLEM CHARACTERISTICS																																		
	Applicable Land Area				Temporal Properties			Spatial Properties		Hydrology				Hydraulics				Quality Processes									Residuals								
	Urban	Agriculture	Forests	Wetlands	Single Storm Events	Continuous Simulation	Annual or Seasonal Average	Single Catchment	Multiple Catchments	Surface/Total Hydrograph Generation	Subsurface Processes	Snowmelt	Dry-weather/Base Flow	Flow Routing in Channels/Pipes	Backwater, Surcharging, Pressure Flow	Flow Controls and Diversions	Storage / Reservoir Routing	Surface Generation	Routing in Channels/Pipes	Sediment / Erosion	Scour / Deposition in Channels/Pipes	Parameter Interaction	Soil/Sediment-Parameter Interaction	Routing through Storages	Treatment/Removal in Storages	Treatment Processes	Organics / BOD / COD	Nitrogen Species	Phosphorus	Suspended Solids	Coliforms	Pesticides	Arbitrary or other Conservative	Arbitrary or other Non-Conservative	Economic Analysis
Hydroscience	●						●	●		●								●						●		●	●	●	●	●	●		●		
HRI	●	●	●				●	●										●		●			●				●	●	●	●	●	●	●	●	
SWMM-Level I	●						●	●		●			●					●									●	●	●	●					●
EPARRB	●	●	●	●	●		●	●										●		●							●	●	●				●		
Simpl. SWMM	●					●			●	●							●									●	●	●	●		●				
ACTMO		●				●			●	●	●	●						●		●	●		●					●	●			●	●	●	
ARM		●			●	●			●	●	●	●								●		●	●					●	●	●		●	●	●	
HSP	●	●	●		●	●			●	●	●	●	●	●		●	●	●	●	●				●			●	●	●	●			●		
NPS	●	●	●	●		●			●	●	●	●						●		●			●				●						●		
QQS	●				●	●			●	●			●	●	●	●	●	●	●					●	●	●							●		
STORM	●					●		●		●		●	●				●	●		●				●	●	●	●	●	●	●	●				
AGRUN		●			●				●	●	●			●				●	●	●							●			●	●		●		
CAREDAS	●				●				●	●			●	●	●	●	●		●					●									●	●	
SWMM	●				●	●			●	●		●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●		●		●

TABLE D-1
Commonly Used Surface Water Runoff Models

Model Name	Commonly Used Acronym	Originator
SCREENING PROCEDURES		
Hydroscience Simplified Model	---	Hydroscience, Inc., Westwood, N.J.
Storm Water Management Model, Level I	SWMM-Level I	Dept. of Environmental Engineering Science, University of Florida, Gainesville, Florida
Midwest Research Institute Loading Functions	MRI	Midwest Research Institute, Kansas City, Missouri
SIMPLIFIED COMPUTER		
Rational Method	---	---
Los Angeles Hydrograph Method	---	City of Los Angeles, Los Angeles, California
Santa Barbara Urban Hydrograph Method	SBUH	Santa Barbara County Flood Control and Water Conservation District, Santa Barbara, California
Environmental Pollution Assessment-Erosion, Sedimentation and Rural Runoff Model	EPARRB	National Environmental Research Center, Environmental Protection Agency, Athens, Georgia
TVA Stormwater Model	---	Division of Water Control Planning, Tennessee Valley Authority, Knoxville, Tennessee
Simplified Storm Water Management Model	Simplified SWMM	Metcalf and Eddy, Inc., Palo Alto, California
CONTINUOUS SIMULATION		
Stanford Watershed Model Variants		
Stanford Watershed Model IV	SWM-IV	Department of Civil Engineering, Stanford University, Palo Alto, California

TABLE D-1 (Continued)
Commonly Used Surface Water Runoff Models

Model Name	Commonly Used Acronym	Originator
Kentucky Watershed Model	KWM	University of Kentucky, Lexington, Kentucky
Self-Optimizing, Continuous Hydrologic Simulation Model	OPSET	University of Kentucky, Lexington, Kentucky
National Weather Service River Forecast System	NWSRFS	Office of Hydrology, National Weather Service, Silver Spring, Maryland
Sacramento Model	---	National Weather Service River Forecast Center and State of California Dept. of Water Resources, Sacramento, California
TVA Daily Flow Model	TVA	Division of Water Control Planning, Tennessee Valley Authority, Knoxville, Tennessee
Hydrocomp Simulation Program	HSP	Hydrocomp, Inc., Palo Alto, California
Pesticide Transport and Runoff Model	PTR	Hydrocomp, Inc., Palo Alto, California
Agricultural Runoff Management Model	ARM	Hydrocomp, Inc., Palo Alto, California
Nonpoint Source Model	NPS	Hydrocomp, Inc., Palo Alto, California
Terrestrial Ecosystem Hydrology Model	TEHM	Oak Ridge National Laboratory, Oak Ridge, Tennessee
Other Continuous Simulation Models		
Agricultural Chemical Transport Model	ACTMO	Agricultural Research Service, USDA, Beltsville, Maryland
Streamflow Synthesis and Reservoir Regulation	SSARR	North Pacific Division, Corps of Engineers, Portland, Oregon

TABLE D-1 (Continued)
Commonly Used Surface Water Runoff Models

Model Name	Commonly Used Acronym	Originator
Conversational Streamflow Synthesis and Reservoir Regulation Program	COSSARR	North Pacific Division, Corps of Engineers, Portland, Oregon
Storage, Treatment, Overflow, and Runoff Model	STORM	Hydrologic Engineering Center, Corps of Engineers, Davis, California
Quantity-Quality-Simulation Model	QQS	Dorsch Consult, Munich, Germany and Toronto, Ontario
MIT Catchment Model	MITCAT	Dept. of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts and Resource Analysis, Inc., Waltham, Massachusetts
SINGLE EVENT SIMULATION		
U.S. Dept. of Agriculture Hydrological Laboratory Model	USDAHL-74	Agricultural Research Service, USDA, Beltsville, Maryland
Problem Oriented Computer Language for Hydrologic Modeling	HYMO	Agricultural Research Service, USDA, Soil and Water Conservation Research Division, Riesel, Texas
Computer Program for Project Formulation Hydrology	TR-20	C-E-I-R, Inc., for Soil Conservation Service, USDA, Washington, D. C.
Urban Hydrology for Small Watersheds	TR-55	Soil Conservation Service, USDA, Washington, D. C.
Agricultural Runoff Model	AGRUN	Water Resources Engineers, Inc. Walnut Creek, California
U.S. Geological Survey Rainfall Runoff Model for Peak Flow Synthesis	USGS	U.S. Geological Survey, Reston, Virginia
Calcul des Reseaux D'assainissement (Calculation of Sewage Networks)	CAREDAS	SOGREAH, Grenoble, France (also New York, New York)

TABLE D-1 (Continued)
Commonly Used Surface Water Runoff Models

Model Name	Commonly Used Acronym	Originator
Chicago Hydrograph Method	CHM (also NERO)	City of Chicago Bureau of Engineering, Chicago, Illinois
Chicago Flow Simulation Program	FSP	Metropolitan Sanitary District of Greater Chicago, Chicago, Illinois
HEC-1 Flood Hydrograph Package	HEC-1	Hydrologic Engineering Center, Corps of Engineers, Davis California
Hydrograph Volume Method	HVM	Dorsch Consult, Munich, Germany and Toronto, Ontario
Illinois Urban Drainage Area Simulator	ILLUDAS	Illinois State Water Survey, Urbana, Illinois
Road Research Laboratory Model	RRL	Transport and Road Research Laboratory, London, United Kingdom
Storm Water Management Model	SWMM	Metcalf and Eddy, Palo Alto, California; University of Florida, Gainesville, Florida; Water Resources Engineers, Walnut Creek, California
University of Cincinnati Urban Runoff Model	UCUR	Dept. of Civil Engineering, University of Cincinnati, Cincinnati, Ohio

FIGURE D-2

Characteristics of Selected Receiving Water Quality Models

MODEL	WATER BODY CHARACTERISTICS										MAJOR PROBLEMS																									
	WATER BODY TYPE					FLOW CONDITIONS					TEMPERATURE			SALINITY				EROSION & SEDIMENTATION			DISSOLVED OXYGEN				EUTROPHICATION			TOXIC SUBSTANCES				BIOLOGICAL EFFECTS				
	Streams	Rivers	Lakes	Estuaries	Offshore Waters	Constant Streamflow	Variable Streamflow	Tidal Action	Steady State Lake Levels	Variable Lake Levels	Ambient Variations	Waste Heat Inputs	Thermal Stratification	Natural Salt Sources	Irrigation Return Flows	Saltwater Intrusion	Salinity Stratification	Bedload Transport	Suspended Solids Transport	Absorbed Residuals Transport	Carbonaceous Oxygen Demand Nonpoint Sources	Carbonaceous Oxygen Demand Point Sources	Nitrogenous Oxygen Demand	Instream Oxygen Demand	Nitrogen Kinetics	Phosphorus Kinetics	Minor Nutrients	Heavy Metals	Pesticides	Refractory/Synthetic Organics	Radioactive Material	Decomposers Inc. Coliforms	Primary Producers	Zooplankton-Invertebrates	Fishes	Ecosystem-Level Indicators
SSM	●	●	●			●															●	●														
SEM		●		●		●										●					●	●														
DOSAG-I	●	●				●															●	●	●													
DOSAG-3	●	●				●								●	●						●	●	●		●	●		●				●	●			
DOSCI	●	●				●								●	●						●	●	●		●	●		●				●	●			
ES001				●		●		●								●					●	●		●								●	●			
QUAL-I	●	●				●															●	●	●									●				
DEM	●	●		●		●	●	●			●	●				●			●	●	●	●	●		●	●	●	●	●	*	*	●	●			
TTM	●	●		●		●	●	●			●	●				●																			
RECEIV	●	●	●	●		●	●	●	●	●						●					●	●	●		●	●	●	●	●	●	●	●				
RIVSCI	●	●		●		●	●	●			●	●				●					●	●	●		●	●	●	●				●	●			
WRECEV	●	●		●		●	●	●								●					●	●	●		●	●	●	●	●	*	*	●				
DRM			●			●	●		●	●	●		●																							
LAKECI			●			●			●				●			●					●	●	●					●								
EPARES			●			●	●		●	●	●	●	●	●	●	●	●				●	●	●		●	●	●	●				●	●			
HSP	●	●	●			●	●		●	●	●	●	●			●					●	●	●		●	●	●	●	●	*	*	●	●	●		
CAFE/DISPER		●	●	●	●		●	●											○						○	○	○	○	○	○	○	○	○	○	○	
EXPLORE-I		●		●		●		●								●			●		●	●	●	●	●	●		●		●		●	●			
PLUME			●	●	●																	●														
HYD/SAL				●	●	●	●	●								●																				
QUAL-II	●	●				●					●	●		●	●				●		●	●	●		●	●		●	●	*	*	●	●			
LAKECO			●			●	●		●	●	●	●	●								●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
EC/WQD				●		●	●	●								●			●	●	●	●	●	●	●	●	●					●	●	●	●	
ESTECO				●	●	●	●	●								●				●	●	●	●	●	●	●	●					●	●	●	●	●
LAKE-I			●						●				●												●	●							●	●	●	
WQRRS	●	●	●			●	●		●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	●					●	●	●	●	
Narragansett Bay Model				●	●	●	●	●			●					●					●	●	●		●	●							●	●	●	

● applicable ; ○ applicable if treated as discrete particles ; * applicable if treated as conservative constituent Abbreviation: Inc., including.

TABLE D-2

Commonly Used Receiving Water Quality Models

Model Name	Commonly Used Acronym	Originator
CHEMICAL REACTION MODELS		
Analytically Integrated		
Streeter-Phelps Dissolved Oxygen Equation	—	Indiana State Board of Health, Bloomington, Indiana
Lumped Parameter Nutrient Budget Model	—	Center for Inland Waters, Canadian Fisheries Research Board, Burlington, Ontario
Long Term Phosphorus Balance Model	—	Battelle Pacific Northwest Labs, Richland, Washington
Steady-State Stream Network Model	SNSIM	U.S. Environmental Protection Agency-Region II, New York, New York
Simplified Stream Model	SSM	Hydroscience, Inc., Westwood, New Jersey
Simplified Estuary Model	SEM	Hydroscience, Inc., Westwood, New Jersey
Numerically Integrated		
Dissolved Oxygen Sag Model	DOSAG-I	Texas Water Development Board, Austin, Texas
Dissolved Oxygen Sag Model (revised version)	DOSAG-3	Water Resources Engineers, Austin, Texas
SCI DOSAG Modification	DOSCI	Systems Control Inc., Palo Alto, California
Estuary Model	ES001	U.S. Environmental Protection Agency-Region II, New York, New York
Automatic Quality Model	AUTO-QUAL	U.S. Environmental Protection Agency, Washington, D. C.

TABLE D-2 (Continued)
Commonly Used Receiving Water Quality Models

Model Name	Commonly Used Acronym	Originator
River Quality Model	QUAL-I	Texas Water Development Board, Austin, Texas
Dynamic Estuary Model	DEM	Water Resources Engineers, Walnut Creek, California
Tidal Temperature Model	TTM	U.S. Environmental Protection Agency, Pacific Northwest Laboratory, Corvallis, Oregon
Receiving Water Model Module of SWMM	RECEIV	Water Resources Engineers, Walnut Creek, California
Receiving Water Model (modification)	RIVSCI	Systems Control, Inc., Palo Alto, California
Receiving Water Model (modification)	WRECEV	Water Resources Engineers, Austin, Texas
Deep Reservoir Model	DRM	Water Resources Engineers, Walnut Creek, California
Lake Ecologic Model (modification of Deep Reservoir Model)	LAKSCI	Systems Control, Inc., Palo Alto, California
Reservoir Water Quality Model	EPARES	Water Resources Engineers, Austin, Texas
Hydrocomp Hydrologic Simulation Program	HSP	Hydrocomp, Inc., Palo Alto, California
Water Quality Feedback Model (HAR03 modification)	FEDBAK03	U.S. Environmental Protection Agency-Region II, New York, New York
Coastal Circulation and Dispersion Model	CAFE/DISPER	Ralph M. Parsons Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
Estuary Water Quality Model	EXPLORE-I	Battelle Pacific Northwest Labs, Richland, Washington
Nutrient Accumulation Model	SPLOTCH	U.S. Environmental Protection Agency, Rochester, New York
Two-Dimensional Stream Mixing Model	---	Water Resources Division, U.S. Geological Survey, Washington, D. C.

TABLE D-2 (Continued)

Commonly Used Receiving Water Quality Models

Model Name	Commonly Used Acronym	Originator
Outfall Plume Model	PLUME	U.S. Environmental Protection Agency, Pacific Northwest Laboratory, Corvallis, Oregon
Willamette River Model	WIRQAS	Water Resources Division, U.S. Geological Survey, Washington, D. C.
Estuary Hydrodynamic/ Salinity Model	HYD/SAL	Texas Water Development Board, Austin, Texas
ECOLOGIC MODELS (All Numerically Integrated)		
River Quality Model (QUAL-I modification)	QUAL-II	Water Resources Engineers, Walnut Creek, California
Lake Ecologic Model (DRM modification)	LAKECO	Water Resources Engineers, Walnut Creek, California
Estuary Ecologic Model	ECOMOD	U.S. Environmental Protection Agency, Washington, D. C.
Estuarine Aquatic Ecologic Model	ESTECO	Texas Water Development Board/ Water Resources Engineers, Austin, Texas
Lake Phytoplankton Model	LAKE-1	Department of Civil Engineering Manhattan College, New York, New York
Eutrophic Lake Quality Model	---	Battelle Pacific Northwest Labs, Richland, Washington
Lake Ecologic Model	CLEAN-CLEANER	International Biological Program, Rensselaer Polytechnic Institute, New York
Water Quality in River-Reservoir Systems	WQRRS	U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California
Naragansett Bay Hydrodynamic Model	---	Department of Ocean Engineering, University of Rhode Island, Narragansett, Rhode Island

Appendix E

Tables of Responses to OTA Survey of Actual and Potential State-Level Model Use

OTA surveyed State agency employees in June, 1980 to determine their current use of models and their perceptions of potential model use; data from Part I of this survey are tabulated in the following pages. The respondents were asked to indicate their use of models in 33 water resource issue areas (left-hand column) for three categories of use (across the top of the tables): A) operations and management, B) planning and policy, and C) other. In these tables, the letter 'X' represents some model use, and 'O' indicates *extensive* model use. The fourth category at the top of the tables, labelled 'N,' reports instances in which State agency personnel specifically indicated that models are not used, or that no potential for model use exists.

	ALABAMA								ALASKA								ARIZONA							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.					X	X	X						X					X			X			
2. Drought/L.Flow					X	X	X						X	X				X			X	X		
3. Streamflow Reg.	X	X			X	X							X					X			X	X		
4. Instream Flow	X	X			X	X							X	X						X				X
5. Dom. Water S.				X	X	X	X						X	X						X				X
6. Irr. Agri.				X	X	X	X													X				
7. Offstream Use				X	X	X	X						X	X						X				X
8. W. Use Effic.				X	X	X	X							X						X				X
9. Urban Runoff				X	X	X	X						X	X						X		X		
10. Erosion/Sed.				X	X	X	X						X	X						X				X
11. Salinity				X	X	X	X													X				X
12. Agric. Runoff				X	X	X	X						X	X						X				X
13. Airborne Poll.				X				X					X	X						X				X
14. Waste L. Alloc.	0	0	X		0	0	X						X	X						X				X
15. Thermal Poll.				X	X	X														X				X
16. Toxic Materials				X	X	X							X	X						X				X
17. Drink.Water Qual.				X				X					X	X						X				X
18. W.Q. Impacts				X	X	X							X	X						X				X
19. G.W. Supplies				X	X	X							X	X				X			X	X		
20. Conjunct. Use				X			X						X	X				0			X	X		
21. Accid. Contam.				X	X	X	X						X	X						X		X		
22. Ag. Poll.-g.w.				X	X	X	X						X	X						X	X	X		
23. W. Disposal-g.w.				X	X	X	X						X	X						X	X	X		
24. Salt W. Intrus.				X	X	X	X						X	X						X				X
25. Water Pricing				X				X										X				X		
26. Costs/Poll.Con.				X				X												X				X
27. Benefit/Cost				X				X												X				X
28. Dev. Implicat.				X				X										X				X		
29. Forecast, Use				X	X	X	X													X		X		
30. Social Imp.				X				X												X		X		
31. Risk/Benefit				X				X												X				X
32. Comp. W. Use				X	X	X	X													X				X
33. Unified R.B.M.	X	X			X	X	X													X				X

	ARKANSAS								CALIFORNIA								COLORADO							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.										X	X		0	X	X		X				X			
2. Drought/L.Flow									X	X	X		X	X	X					X				X
3. Streamflow Reg.									0	0			0	0			X				X			
4. Instream Flow									0	X			0	0						X				X
5. Dom. Water S.									0	0			X	X						X	X			
6. Irr. Agri.									0	0			X	X			X				X			
7. Offstream Use												X	X	X						X				X
8. W. Use Effic.									0	0			X	X						X	X			
9. Urban Runoff												X	X	X						X				X
10. Erosion/Sed.	X	X			X	X			X	X										X				X
11. Salinity										X			X	0	X					X				X
12. Agric. Runoff						X				X			X	X						X				X
13. Airborne Poll.												X				X				X				X
14. Waste L. Alloc.	X	X			X	X						X	X	X	X					X				X
15. Thermal Poll.									X	X										X				X
16. Toxic Materials					X					X			X	X						X				X
17. Drink.Water Qual.					X	X				X			X	X	X					X				X
18. W.Q. Impacts					X	X				X			X	X	X					X				X
19. G.W. Supplies									X	X	X		X	X	X		0				0			
20. Conjunct. Use									X	X	X		X	X	X		0				0			
21. Accid. Contam.											X		X		X					X				X
22. Ag. Poll.-g.w.											X		X	X	X					X				X
23. W. Disposal-g.w.										X	X		X	X						X				X
24. Salt W. Intrus.										X	X		X	X	X					X				X
25. Water Pricing										X			X	X						X				X
26. Costs/Poll.Con.												X				X				X				X
27. Benefit/Cost										X			X	X						X				X
28. Dev. Implicat.										X				X						X				X
29. Forecast. Use										X	X					X				X				X
30. Social Imp.										X						X				X				X
31. Risk/Benefit												X	X		X					X				X
32. Comp. W. Use									X	X			X	X						X				X
33. Unified R.B.M.									X	X			0	0						X				X

	CONNECTICUT								DELAWARE								FLORIDA							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.	X	X			X	X						X									X	X	X	
2. Drought/L.Flow				X	X	0						X					0	X	X		X	X	X	
3. Streamflow Reg.	X				X	X						X					0	0			X	X		
4. Instream Flow		X			X	X						X						X			X	X		
5. Dom. Water S.		X			X	X						X		X			X	X			X	X		
6. Irr. Agri.				X				X				X						X				X		
7. Offstream Use				X		X	X					X								X				X
8. W. Use Effic.				X	X	X						X										X		
9. Urban Runoff		X			X	X	X					X					X	X			X	X		
10. Erosion/Sed.		X			X	X	X					X									X	X		
11. Salinity		0						X				X			X						X	X	X	
12. Agric. Runoff		X			X	X	X					X									X	X		
13. Airborne Poll.	X	X			X	X	X					X								X				X
14. Waste L. Alloc.	0	0	X		0		X					X										X		
15. Thermal Poll.				X	X		0					X										X	X	
16. Toxic Materials				X	X	0	X					X	X	X								X	X	
17. Drink.Water Qual.	X				X	X	X					X		X										
18. W.Q. Impacts	X	X			X	0	X					X										X	X	
19. G.W. Supplies		X			0	0	X					X		X			X	X			X	X		
20. Conjunct. Use		X			0	0	X					X					X	X			X	X		
21. Accid. Contam.	X	X			X	X	X					X	X	X								X		
22. Ag. Poll.-g.w.		X				X						X	X	X								X		
23. W. Disposal-g.w.	X				X	X	X					X	X	X			X				X	X		
24. Salt W. Intrus.				X				X				X	X	X			X	X			X	X		
25. Water Pricing	X				X	X	X					X									X	X		
26. Costs/Poll. Co.				X	X	X						X												
27. Benefit/Cost		X			X	X	X					X									X	X		
28. Dev. Implicat.				X	X	X						X						X			X	X		
29. Forecast. Use		X			X	X						X									X	X		
30. Social Imp.				X	X	X						X									X	X		
31. Risk/Benefit				X	X	X						X									X	X		
32. Comp. W. Use				X	X	X	X					X									X	X		
33. Unified R.B.M.				X	X	X	X					X									X	X		

	GEORGIA								HAWAII								IDAHO							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.				X								X		X	X					X				X
2. Drought/L.Flow				X							X		X	X	X					X				X
3. Streamflow Reg.				X		X						X	X	X						X				X
4. Instream Flow				X								X	X	X						X				X
5. Dom. Water S.				X		X			X				X	X						X	X	X		
6. Irr. Agri.				X							X			X						X				X
7. Offstream Use				X											X					X	X	X		
8. W. Use Effic.				X								X	X	X						X	X	X		
9. Urban Runoff				X		X								X	X					X	X	X		
10. Erosion/Sed.				X								X		X	X					X	X	X		
11. Salinity				X								X	X	X						X	X	X		
12. Agric. Runoff				X								X	X	X	X					X	X	X		
13. Airborne Poll.				X										X	X		0	0			0	0		
14. Waste L. Alloc.	0	0			0	0							X	X	X		0	X			X	X		
15. Thermal Poll.				X								X			X		X				X	X		
16. Toxic Materials				X								X		X	X		X	X			X	X		
17. Drink.Water Qual.				X									X	X	X					X	X	X		
18. W.Q. Impacts				X		X								X	X		X	X			X	X		
19. G.W. Supplies	0								X	X	X		X	X	X					X				X
20. Conjunct. Use				X								X	X	X	X					X				X
21. Accid. Contam.				X								X	X	X	X					X	X	X		
22. Ag. Poll.-g.w.				X								X	X	X	X					X	X	X		
23. W. Disposal-g.w.				X								X	X	X	X					X	X	X		
24. Salt W. Intrus.				X								X	X	X	X					X				X
25. Water Pricing				X								X		X	X					X				X
26. Costs/Poll.Con.				X								X	X	X	X					X	X	X		
27. Benefit/Cost				X		X						X		X	X					X	X	X		
28. Dev. Implicat.				X							X				X					X				X
29. Forecast. Use				X					X	X			X	X						X	X	X		
30. Social Imp.				X								X			X					X	X	X		
31. Risk/Benefit				X								X	X	X	X					X	X	X		
32. Comp. W. Use				X								X	X	X	X					X	X	X		
33. Unified R.B.M.	0	0			0	0						X		X	X					X	X	X		

	ILLINOIS								INDIANA								IOWA							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.	X	X			X	X			O	O	X		O	O	X		X	O					X	
2. Drought/L.Flow	X	X	X		X	X	X					X	X	X				X			X		X	
3. Streamflow Reg.	X	X			X	X			X				X							X	X	X		
4. Instream Flow			X		X	X						X		X						X		X	X	
5. Dom. Water S.	X	X	X		X	X						X		X						X	X	X		
6. Irr. Agri.				X	X							X		X						X	X		X	
7. Offstream Use				X	X							X		X						X		X	X	
8. W. Use Effic.	X		X		X	X						X		X						X	X	X	X	
9. Urban Runoff				X				X		X				X				X					X	
10. Erosion/Sed.				X				X				X		X						X	X	X	X	
11. Salinity				X				X				X				X				X				X
12. Agric. Runoff				X				X				X			X					X				
13. Airborne Poll.				X				X				X				X				X				
14. Waste L. Alloc.	X				X	X			O	O			O	X						X				
15. Thermal Poll.				X	X						X		X							X				
16. Toxic Materials				X				X				X	X							X				
17. Drink.Water Qual.				X				X				X	X							X				
18. W.Q. Impacts				X	X							X	X							X				
19. G.W. Supplies	X	X			X	X				X			X				X	X						
20. Conjunct. Use	X				X	X						X	X	X						X	X	X		
21. Accid. Contam.				X	X							X	X							X	X	X		
22. Ag. Poll.-g.w.				X				X				X		X						X	X	X		
23. W. Disposal-g.w.				X				X				X								X	X	X		
24. Salt W. Intrus.	X				X															X		X		
25. Water Pricing	X				X	X														X	X	X		
26. Costs/Poll.Con.				X				X												X				
27. Benefit/Cost	X	X			X	X														X				
28. Dev. Implicat.				X			X													X	X	X		
29. Forecast. Use	X	X			X	X														X	X	X		
30. Social Imp.				X				X												X				
31. Risk/Benefit				X	X	X														X				
32. Comp. W. Use				X	X	X														X	X	X		
33. Unified R.B.M.				X	X	X														X	X	X		

	KANSAS								**KENTUCKY**								**LOUISIANA**							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.				X		X			X	X			X	X			O	X			X	X		
2. Drought/L.Flow	X	X	X		X	X			X	O			X	X	X					X	X	X		
3. Streamflow Reg.	X	X			X	X			X				X	X			O				O			
4. Instream Flow		X			X	X	X					X	X	X						X	X	X		
5. Dom. Water S.	X	X	X			X						X	X	X	X					X	X	X	X	
6. Irr. Agri.	X	X	X			X						X			X					X	X	X		
7. Offstream Use	X	X	X			X						X	X	X	X					X	X	X		
8. W. Use Effic.	X	X	X			X						X		X	X					X	X		X	
9. Urban Runoff		X			X	X				X			X	X						X	X	X	X	
10. Erosion/Sed.		X			X	X			X	X	X		O	O	O					X	X	X		
11. Salinity		X				X			X	X	X		X	X	X					X	X	X		
12. Agric. Runoff	X				X							X	X	X	X			X			X	X	X	
13. Airborne Poll.				X				X	X	X			X	X						X	X	X	X	
14. Waste L. Alloc.	X				X	X			X	X			X	X	X		O	X			X	X		
15. Thermal Poll.				X	X	X						X	X	X			X				X	X		
16. Toxic Materials				X		X						X	O	O	O					X	X	X	X	
17. Drink.Water Qual.				X		X						X	O	O	O					X	X	X	X	
18. W.Q. Impacts				X		X			X	X			O	O	O					X	X	X	X	
19. G.W. Supplies	X	X	X		X	X			X	X	X		O	O	O		X	X			O	O		
20. Conjunct. Use	X	X	X			X						X	X	X	X		X	X			O	O		
21. Accid. Contam.				X				X				X	X	X	X					X	X	X		
22. Ag. Poll.-g.w.				X		X						X	X	X						X	X	X		
23. W. Disposal-g.w.				X		X						X	X	X	X					X	X	X		
24. Salt W. Intrus.				X				X				X			X					X	X	X		
25. Water Pricing				X	X	X	X					X		X						X	X	X		
26. Costs/Poll.Con.				X				X				X	X	X	X					X	X	X		
27. Benefit/Cost				X	X	X	X					X		X						X		X		
28. Dev. Implicat.		X	X		X							X		X						X				
29. Forecast. Use		X	X		X	X						X		X						X	X	X		
30. Social Imp.				X				X				X		X								X		
31. Risk/Benefit				X				X				X		X						X		X		
32. Comp. W. Use		X	X		X	X						X	X	X						X		X		
33. Unified R.B.M.		X	X		X	X						X	X	X						X	X	X		

	MAINE								**MARYLAND**								**MASSACHUSETTS**							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.	X	X			X	X			X	X			X	X						X				X
2. Drought/L.Flow	X	X			X	X												X			X			
3. Streamflow Reg.	X	X				X												X			X			
4. Instream Flow				X	X	X				X								X			X			
5. Dom. Water S.		X			X	X												X			X			
6. Irr. Agri.				X	X	X														X				X
7. Offstream Use				X	X															X				X
8. W. Use Effic.				X	X	X	X													X		X	X	
9. Urban Runoff				X	X	X				X				X						X	X	X	X	
10. Erosion/Sed.				X	X	X				X				X						X	X	X	X	
11. Salinity				X		X			X	X			X	X						X	X	X	X	
12. Agric. Runoff				X	X	X	X			X				X						X	X	X	X	
13. Airborne Poll.				X	X	X	X		X	X				X						X		X		
14. Waste L. Alloc.				X	X	X			X	X			X	X			X	X			X	X		
15. Thermal Poll.				X	X		X			X						X				X	X	X		
16. Toxic Materials				X	X		X			X				X						X	X	X		
17. Drink.Water Qual.	X	X			X	X				X				X						X	X	X		
18. W.Q. Impacts				X	X	X				X			X	X					X		X	X		
19. G.W. Supplies				X	X	X				X			X	X			X	X			X	X		
20. Conjunct. Use		X			X	X						X				X			X		X	X		
21. Accid. Contam.	X				X	X						X	X	X						X	X	X		
22. Ag. Poll.-g.w.				X	X	X						X	X	X						X	X	X		
23. W. Disposal-g.w.				X	X	X	X					X		X						X	X	X		
24. Salt W. Intrus.				X	X	X						X		X						X		X		
25. Water Pricing				X	X	X						X		X						X		X		
26. Costs/Poll.Con.				X		X						X		X						X		X		
27. Benefit/Cost				X	X	X						X		X						X		X		
28. Dev. Implicat.				X		X						X		X						X		X		
29. Forecast. Use				X	X	X						X		X						X		X		
30. Social Imp.				X		X						X		X						X			X	
31. Risk/Benefit				X	X	X						X		X						X		X		
32. Comp. W. Use				X	X	X				X				X						X		X		
33. Unified R.B.M.				X	X	X				X				X						X	X	X		

	MICHIGAN								MINNESOTA								MISSISSIPPI							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.		X			X	X				X				X			X				X	X		
2. Drought/L.Flow	X				X							X	X	X				X			X	X		
3. Streamflow Reg.				X				X	X					X			X	X			X	X		
4. Instream Flow				X	X	X			X	X			X	X						X		X		
5. Dom. Water S.				X		X						X	X	X						X				X
6. Irr. Agri.				X	X	X						X	X	X					X			X		
7. Offstream Use				X				X				X	X	X						X		X		
8. W. Use Effic.				X				X				X	X	X						X		X		
9. Urban Runoff				X	X	X			X	X			X	X	X					X	X	X		
10. Erosion/Sed.				X	X	X			X	X			X	X	X					X	X	X		
11. Salinity				X				X				X	X							X	X	X		
12. Agric. Runoff				X	X	X			X	X			X	X	X					X		X		
13. Airborne Poll.				X	X	X						X	X	X	X					X	X	X		
14. Waste L. Alloc.				X	X	X			O	X			X	X	X		X	O			X	X		
15. Thermal Poll.				X	X	X						X	X	X	X		X	X			X	X		
16. Toxic Materials				X	X	X			X	X			X	X	X			X			X	X		
17. Drink.Water Qual.						X			X	X			X	X	X					X	X	X		
18. W.Q. Impacts				X	X	X			X	X			X	X	X					X	X	X		
19. G.W. Supplies				X	X	X						X	X	X	X			X			X	X		
20. Conjunct. Use				X	X	X						X	X	X	X					X	X	X		
21. Accid. Contam.				X	X	X	X					X	X	X	X					X	X	X		
22. Ag. Poll.-g.w.				X	X	X						X	X	X	X					X	X	X		
23. W. Disposal-g.w.				X	X	X						X	X	X	X					X	X	X		
24. Salt W. Intrus.				X				X				X								X	X	X		
25. Water Pricing				X				X				X	X	X						X		X		
26. Costs/Poll.Con.				X				X				X	X	X						X		X		
27. Benefit/Cost				X				X				X	X	X						X		X		
28. Dev. Implicat.				X				X		X			X	X						X		X		
29. Forecast. Use				X						X			X	X						X		X		
30. Social Imp.				X								X	X	X						X		X		
31. Risk/Benefit				X								X	X	X						X		X		
32. Comp. W. Use	X				X	X						X	X	X						X		X		
33. Unified R.B.M.	X				X	X						X	X	X						X		X		

	MISSOURI								**MONTANA**								**NEBRASKA**							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.				X	X	X	X		O	X			O	X			X				X			
2. Drought/L.Flow				X	X	X	X		O															
3. Streamflow Reg.				X	X	X	X		O									X				X		
4. Instream Flow				X	X		X				X		X	X					X			X		
5. Dom. Water S.				X	X	X	X					X								X				
6. Irr. Agri.				X	X	X						X					X	X			X	X		
7. Offstream Use				X	X	X						X							X					
8. W. Use Effic.				X	X	X	X					X					X	X						
9. Urban Runoff					X	X						X								X				
10. Erosion/Sed.					X	X								X					X			X		
11. Salinity					X	X						X								X				
12. Agric. Runoff					X	X						X						X	X			X	X	
13. Airborne Poll.	X	X	X		X	X	X					X					X	X			X	X		
14. Waste L. Alloc.					X	X						X								X				
15. Thermal Poll.					X	X						X								X				
16. Toxic Materials					X	X						X								X				
17. Drink.Water Qual.				X	X	X						X								X				X
18. W.Q. Impacts					X	X						X						X	X		X	X		
19. G.W. Supplies				X	X	X	X		X					X			O	O			X	O		
20. Conjunct. Use				X	X	X	X		X					X			O	X			X	X		
21. Accid. Contam.				X	X	X	X					X								X				
22. Ag. Poll.-g.w.					X	X	X					X		X			X	X	X		X	X		
23. W. Disposal-g.w.					X	X						X								X				
24. Salt W. Intrus.					X	X						X								X				X
25. Water Pricing					X	X	X					X						X				X		
26. Costs/Poll.Con.				X	X	X						X								X				
27. Benefit/Cost					X	X						X								X				
28. Dev. Implicat.					X	X						X						X				X		
29. Forecast. Use					X	X			X	X														
30. Social Imp.				X	X	X	X					X						X				X		
31. Risk/Benefit						X			X															
32. Comp. W. Use					X	X						X												
33. Unified R.B.M.					X	X	X			X														

	NEVADA								NEW HAMPSHIRE								NEW JERSEY							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.	X	0																X			X			
2. Drought/L.Flow	X	X															X	0						
3. Streamflow Reg.	X	X															0							
4. Instream Flow	X	0																0						
5. Dom. Water S.	X	X										X				X				X				
6. Irr. Agri.	X	X																		X				
7. Offstream Use	X	X																		X				
8. W. Use Effic.	X	X										X				X				X				
9. Urban Runoff	X				X							X				X						X		
10. Erosion/Sed.	X				X	X						X				X						X		
11. Salinity		X						X				X				X	X	X	X		X	X	X	
12. Agric. Runoff	X	X			X							X				X						X	X	
13. Airborne Poll.	X	X			X				X				X									X		
14. Waste L. Alloc.	0	0			X							X					X	X	X		X	X	X	
15. Thermal Poll.	X	0			X							X										X	X	
16. Toxic Materials	X	X				X						X				X					X	X	X	
17. Drink.Water Qual.		X			X	X						X				X		X				X		
18. W.Q. Impacts	0	0			X	X						X					X	X						
19. G.W. Supplies	X	X			X	X						X					X	X						
20. Conjunct. Use	X	X			X	X						X					X	X						
21. Accid. Contam.				X	X	X						X					X	X						
22. Ag. Poll.-g.w.		X			X							X					X	X						
23. W. Disposal-g.w.		X			X	X						X					X	X						
24. Salt W. Intrus.				X				X													X	X		
25. Water Pricing	X	X			X	X												X			X	X	X	
26. Costs/Poll.Con.		X																X						
27. Benefit/Cost	X	0																X						
28. Dev. Implicat.	X				X	X																		
29. Forecast. Use		X			X	X																		
30. Social Imp.				X	X																			
31. Risk/Benefit				X	X																			
32. Comp. W. Use		X			X	X												X			X			
33. Unified R.B.M.		X			X	X												X			X			

	NEW MEXICO								NEW YORK								NORTH CAROLINA							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.	X				X	X				X			X						X		X	X	X	
2. Drought/L.Flow	X				X	X			X	O							X	X				X	X	
3. Streamflow Reg.	X				X	X			O								X	X			X	X	X	
4. Instream Flow				X		X				O								X	X		X	X	X	
5. Dom. Water S.	X	X			X	X						X						X			X	X		
6. Irr. Agri.	X	X			X	X						X							X		X	X	X	
7. Offstream Use	X	X			X	X						X							X		X	X		
8. W. Use Effic.	X	X			X	X						X								X	X	X	X	
9. Urban Runoff		X				X				X	X								X		X	X	X	
10. Erosion/Sed.				X		X				X	X								X		X	X		
11. Salinity		X				X													X		X	X		
12. Agric. Runoff		X				X			X	X									X		X	X		
13. Airborne Poll.	X	X			X	X				X	X								X		X	X		
14. Waste L. Alloc.	X	X			X	X			X	X							O	X			X	X		
15. Thermal Poll.				X	X	X											X	X	X		X	X		
16. Toxic Materials	X	X			X	X									X				X		X	X		
17. Drink.Water Qual.				X		X											X	X			X	X	X	
18. W.Q. Impacts	X	X			X	X				X	X						X	X	X		X	X	X	
19. G.W. Supplies	O	X			X	X				O										X	X	X	X	
20. Conjunct. Use	O	X			X	X								X						X	X	X	X	
21. Accid. Contam.				X	X	X														X	X	X	X	
22. Ag. Poll.-g.w.				X		X														X	X	X	X	
23. W. Disposal-g.w.				X		X														X		X	X	
24. Salt W. Intrus.	X	X			X	X														X	X	X	X	
25. Water Pricing				X		X						X		X						X		X	X	
26. Costs/Poll.Con.				X		X						X	X	X						X		X	X	
27. Benefit/Cost	X	X				X				O			X	X	X					X		X	X	
28. Dev. Implicat.				X		X						X	X	X	X					X		X	X	
29. Forecast. Use				X		X				X			X							X	X	X	X	
30. Social Imp.				X		X						X	X	X	X					X		X		
31. Risk/Benefit				X		X						X	X	X	X					X		X		
32. Comp. W. Use				X		X						X		X	X					X		X	X	
33. Unified R.B.M.				X		X				O			X	X				X			X	X		

	NORTH DAKOTA								OHIO								OKLAHOMA							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.		X				X			0	0			0	0						X	X	X		
2. Drought/L.Flow				X	X	X			0	0			0	0						X	X	X		
3. Streamflow Reg.	X				0	X			0	0			0	0			X				X	X		
4. Instream Flow				X	X	X						X	X	X				X			X	X		
5. Dom. Water S.	X				X	X				X			X	X				X			X	X		
6. Irr. Agri.				X		X						X	X	X				X			X	X		
7. Offstream Use	X				X	X						X				X		X			X	X	X	
8. W. Use Effic.				X	X	X						X	X	X				X			X	X		
9. Urban Runoff									X	X			0	0						X	X	X		
10. Erosion/Sed.										X			X	X				X			X	X		
11. Salinity												X				X				X	X	X		
12. Agric. Runoff										X			X	X				X			X	X		
13. Airborne Poll.									0	0			0	0				X			X	X		
14. Waste L. Alloc.									0	0			0	0				X			X	X		
15. Thermal Poll.									0	0			0	0						X	X	X		
16. Toxic Materials												X	0	0			X				X	X		
17. Drink.Water Qual.												X	X	X			X				X	X		
18. W.Q. Impacts									0	0			0	0						X	X	X		
19. G.W. Supplies	0	X			X	X			0	0			0	0			X	X			X	X	X	
20. Conjunct. Use				X	X	X			X	X			X	X			X				X	X		
21. Accid. Contam.				X	X	X						X				X				X	X	X		
22. Ag. Poll.-g.w.				X	X	X														X		X		
23. W. Disposal-g.w.				X	X	X			X	X			X	X						X		X		
24. Salt W. Intrus.				X				X				X				X				X		X		
25. Water Pricing						X						X	X	X						X		X		
26. Costs/Poll.Con.						X						X	X	X						X		X		
27. Benefit/Cost						X						X	X	X						X		X		
28. Dev. Implicat.						X						X	X	X				X			X	X		
29. Forecast. Use		0										X				X				X		X		
30. Social Imp.	X	0			X	X						X				X				X				X
31. Risk/Benefit												X	X	X						X				X
32. Comp. W. Use		X										X								X		X		
33. Unified R.B.M.												X						X			X	X		

	OREGON								PENNSYLVANIA								RHODE ISLAND							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.				X	X	X						X	X	X			X	X			X	X		
2. Drought/L.Flow				X	X	X						X	X	X						X	X	0		
3. Streamflow Reg.				X	X	X			0	X							X				X	X		
4. Instream Flow				X	X	X				X				X				X			X	X		
5. Dom. Water S.				X	X	X			X	X								X			X	X		
6. Irr. Agri.				X	X	X			X	X										X				X
7. Offstream Use				X	X	X				X										X		X	X	
8. W. Use Effic.												X	X	X						X	X	X		
9. Urban Runoff									X				X	X						X	X	X		
10. Erosion/Sed.												X	X	X						X				X
11. Salinity												X	X	X						X				X
12. Agric. Runoff												X	X	X						X				X
13. Airborne Poll.									X	X			X	X						X		X		
14. Waste L. Alloc.									0	X			X	X			X	X			X	X		
15. Thermal Poll.									0	X			X	X				X			X	X		
16. Toxic Materials									0	0			X	X						X	X			
17. Drink.Water Qual.									0	0			X	X						X				X
18. W.Q. Impacts									0	0			X	X						X	X	X		
19. G.W. Supplies	X				X				X	X			X	X			0	0						
20. Conjunct. Use	X					X						X	X	X			0	0						
21. Accid. Contam.					X	X						X	X				X	X						
22. Ag. Poll.-g.w.					X	X						X	X	X										
23. W. Disposal-g.w.					X	X						X	X	X			X	X						
24. Salt W. Intrus.						X						X				X	X	X						
25. Water Pricing												X		X										
26. Costs/Poll.Con.						X						X	X	X							X	X		
27. Benefit/Cost						X				0			X	X	X						X	X		
28. Dev. Implicat.						X						X	X	X	X									
29. Forecast. Use						X				X			X				X	X						
30. Social Imp.						X						X	X	X	X									
31. Risk/Benefit						X						X	X	X	X		X	X						
32. Comp. W. Use						X						X		X	X						X	X		
33. Unified R.B.M.						X				0			X	X			0	0						

	SOUTH CAROLINA								SOUTH DAKOTA								TENNESSEE							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.											X				X					X				X
2. Drought/L.Flow																				X				X
3. Streamflow Reg.											X		X	X						X				X
4. Instream Flow																				X				X
5. Dom. Water S.																				X		X		
6. Irr. Agri.																				X				X
7. Offstream Use																				X				X
8. W. Use Effic.																				X				X
9. Urban Runoff			X		X		X													X		X		
10. Erosion/Sed.			X		X		X		X	X			X	X	X					X		X		
11. Salinity		X			X	X	X													X				X
12. Agric. Runoff			X		X		X													X		X		
13. Airborne Poll.				X	X		X																	
14. Waste L. Alloc.	0				0				X				X	X	X			0				0		
15. Thermal Poll.	X				X															X		0		
16. Toxic Materials	X				X															X		X		
17. Drink.Water Qual.	X				X	X	X													X				X
18. W.Q. Impacts	X		X		X		X													X		X	X	
19. G.W. Supplies				X	X	X			0	X										X				X
20. Conjunct. Use				X	X	X			X	X										X				X
21. Accid. Contam.				X	X	X							X							X				X
22. Ag. Poll.-g.w.				X	X	X							X							X		X		
23. W. Disposal-g.w.				X	X	X						X								X		X		
24. Salt W. Intrus.				X	X	X						X								X				X
25. Water Pricing				X	X	X			X				X	X						X				X
26. Costs/Poll.Con.																				X			X	
27. Benefit/Cost									X											X			X	
28. Dev. Implicat.																				X			X	
29. Forecast. Use																				X				X
30. Social Imp.																				X				X
31. Risk/Benefit																				X			X	
32. Comp. W. Use				X	X	X														X			X	
33. Unified R.B.M.																				X		X	X	

	TEXAS								UTAH								VERMONT							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.	O	O						X	X	X			X	X	X					X	X	X		
2. Drought/L.Flow		X								X	X		X	X	X			X			X	X		
3. Streamflow Reg.					X	X			X	X	X		X	X	X					X	X	X		
4. Instream Flow	O	O				X				X	X		X	X	X					X	X	X		
5. Dom. Water S.		X			X	X			X	X	X		X	X	X					X				
6. Irr. Agri.	X	O	X		X	X	X		X	X	X		X	X	X					X				
7. Offstream Use		O	X		X	X	X		X	X	X		X	X	X					X				
8. W. Use Effic.	O	O	X		X	X	X		X		X		X	X	X					X				
9. Urban Runoff		O			X	X	X				X		X	X	X					X	X	X		
10. Erosion/Sed.			X		X	X					X		X	X	X					X				
11. Salinity		X			X	X				X	X		X	X	X					X				
12. Agric. Runoff		O				X				X	X		X	X	X			X						
13. Airborne Poll.	X	X	X		X	X				X	X		X	X	X		O	O			O	O		
14. Waste L. Alloc.				X						X	X		X	X	X		O	X			O	O		
15. Thermal Poll.	X	O	X		X	X	X			X	X		X	X	X					X	X	X		
16. Toxic Materials	O	O	X		X	X						X	X	X	X					X	X	X		
17. Drink.Water Qual.		O			X	X	X					X	X	X	X					X	X	X		
18. W.Q. Impacts		X			X	X				X	X		X	X	X						X	X		
19. G.W. Supplies	X	O	X		X	X	X		X	X	X		X	X	X					X				X
20. Conjunct. Use	X	O				X			X	X	X		X	X	X					X				
21. Accid. Contam.			X		X	X						X	X	X	X					X	X	X		
22. Ag. Poll.-g.w.				X	X	X	X					X	X	X	X					X				
23. W. Disposal-g.w.				X	X	X	X				X		X	X	X					X				
24. Salt W. Intrus.				X	X	X	X				X		X	X	X					X				
25. Water Pricing		X				X				X	X		X	X	X					X				
26. Costs/Poll.Con.										X	X		X	X	X					X				
27. Benefit/Cost		O				X				X	X			X	X					X				
28. Dev. Implicat.		O				X				X	X			X	X					X				
29. Forecast. Use		O				X				X	X		X	X	X					X				
30. Social Imp.										X	X		X	X	X					X				
31. Risk/Benefit		X				X				X	X		X	X	X					X				
32. Comp. W. Use		X				X				X	X			X	X					X				
33. Unified R.B.M.										X	X		X	X	X					X		X		

	VIRGINIA								WASHINGTON								WEST VIRGINIA							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.				X					X				X	X			X	O			X	O		
2. Drought/L.Flow		X	X						X				X	X			X	O			X	O		
3. Streamflow Reg.	X	X	X						X				X	X			X	O			X	O		
4. Instream Flow				X					X	O			X	X									X	
5. Dom. Water S.				X					X	X			X	X										
6. Irr. Agri.				X					X	X			X	X										
7. Offstream Use				X								X	X											
8. W. Use Effic.				X						X				X									X	
9. Urban Runoff				X													X	X			X	X		
10. Erosion/Sed.				X													X	X			X	X		
11. Salinity				X																				
12. Agric. Runoff				X																				
13. Airborne Poll.				X																				
14. Waste L. Alloc.	X	O	X														X	O			X	O		
15. Thermal Poll.				X													X	O			X	O		
16. Toxic Materials				X													X	X			X	X		
17. Drink.Water Qual.				X																				
18. W.Q. Impacts	X	X	X														X	O			X	O		
19. G.W. Supplies	O	X	X						X	X						X								
20. Conjunct. Use				X						X			X	O				X				O		
21. Accid. Contam.				X																			X	
22. Ag. Poll.-g.w.				X														X				X		
23. W. Disposal-g.w.				X														X				O		
24. Salt W. Intrus.				X														X				X		
25. Water Pricing				X								X		X										
26. Costs/Poll.Con.				X																				
27. Benefit/Cost				X								X												
28. Dev. Implicat.												X										X		
29. Forecast. Use				X								X		X								X		
30. Social Imp.				X								X												
31. Risk/Benefit				X								X												
32. Comp. W. Use				X								X												
33. Unified R.B.M.				X										X				X				X		

	WISCONSIN								WYOMING								WASHINGTON, D.C.							
	Existing				Potential				Existing				Potential				Existing				Potential			
	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N	A	B	C	N
1. Flood Forecast.	X	X			X	X						X	X	X	X			X						X
2. Drought/L.Flow	X	X			O	X						X	X	X	X		X	X	X			X		
3. Streamflow Reg.	X	X	X			X	X					X	X	X	X			X						X
4. Instream Flow		X			O	X						X	X		X					X				X
5. Dom. Water S.				X				X				X	X	X	X			X						X
6. Irr. Agri.				X	O	X						X	X	X						X				X
7. Offstream Use				X	O	X						X	X	X						X				X
8. W. Use Effic.				X			X					X	X	X	X					X				X
9. Urban Runoff		X	X		X	X	X		X	X	X		X	X	X		X	O						
10. Erosion/Sed.	X	X	X			X			X	X	X		X	X	X			X						X
11. Salinity				X				X		X	X			X	X					X				
12. Agric. Runoff		X				X				X	X			X	X			O						X
13. Airborne Poll.		X	X		X	X						X				X				X		X		
14. Waste L. Alloc.	O	O				X			X				X				X	X				X		
15. Thermal Poll.	X	X				X			X				X							X			X	
16. Toxic Materials				X		X			X				X							X		X		
17. Drink.Water Qual.				X		X						X				X		X				X		
18. W.Q. Impacts		X			X	X			X	X	X		X	X	X			X				X		
19. G.W. Supplies		X			X	X							X	X						X				X
20. Conjunct. Use		X			X	X			X	X	X		X	X	X					X				X
21. Accid. Contam.				X				X	X	X	X		X	X	X					X				X
22. Ag. Poll.-g.w.				X	X	X			X	X	X		X	X	X					X				X
23. W. Disposal-g.w.				X	X	X			X	X	X		X	X	X					X				X
24. Salt W. Intrus.				X				X				X				X				X				X
25. Water Pricing				X		X						X				X		X						X
26. Costs/Poll.Con.		X	X		X	X					X				X		X	X						X
27. Benefit/Cost		X				X					X				X			X				X		
28. Dev. Implicat.		X			O	X					X				X			X						X
29. Forecast. Use		X			X	X						X				X		X				X		
30. Social Imp.				X		X						X				X		X						X
31. Risk/Benefit		X				X	X					X				X		X				X		
32. Comp. W. Use				X		X					X				X			X				X		
33. Unified R.B.M.		O				X					X				X			X				X		

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